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Economy-wide material flows and environmental policy

An analysis of indicators and policy uses for economy-wide material flow policy

Report

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Foreword

For their constructive comments the authors thank the members of the advisory committee: Annemarth Idenburg of the National Institute for Public Health and the Environment (RIVM, Environment and Nature Planning Office), Henk Strietman of the Ministry of Housing, Spatial Planning and the Environment (VROM, Climate Change and Industry directorate), Willem Willart of the same ministry (Substances, Waste and Radiation Protection directorate) and Jan-Paul van Soest, consultant.

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Executive Summary

Brief synopsis and main conclusions

It is common knowledge that materials use is often associated with a host of environmental problems. After all, given the impossibility of limitless recycling, all the materials flowing into an economy will inevitably leave it sooner or later as wastes or emissions.

For this and other reasons there is growing interest in establishing some form of ‘economy-wide material flow policy’, i.e. policy addressing the overall flows of materials through the economy. This has been addressed, alternatively, as ‘resource policy’. In the Netherlands as well as at the EU level, plans have been announced to establish such an economy-wide material flow policy, on the reasoning that by reducing the magnitude and/or composition of material flows, the environmental burden associated with those flows can likewise be reduced.

The current research report deals with the question whether it is possible and desirable to design an element of a material flow policy revolving around improved resource productivity that satisfies the requirements for a dematerialisation policy stipulated in the 4th National Environmental Policy Plan (NEPP4).

The report concludes that economy-wide material flow policies can serve to supplement existing materials-related policies, which often focus on a specific link in the supply chain (raw materials policy, product policy, waste policy). By linking up these policy fields, greater policy coherence can be achieved as well as a better understanding of the role of materials in the economy and their environmental impact. Another benefit of an integrated, life-cycle approach is that the ‘foreign’ environmental impacts of materials consumed here are brought into the picture. Indeed, social and political concern about the global impact of our domestic consumption patterns is one of the very motives for establishing an economy-wide material flow policy.

Indicators provide a means of monitoring policy progress and have been more or less mandatory in the Netherlands since the so-called VBTB ministerial guidelines ('From policy budget to policy accountability') were introduced a number of years ago. It is obviously important that indicators properly match the policy objective they are designed to monitor. In the international scientific literature and at the OECD, indicators have been proposed in which total material flows are aggregated on the basis of tonnage consumption to yield an estimate of the associated environmental burden. As some of the analysis reported here demonstrates, however, weight is a very poor indicator of the environmental impact of the materials flowing through a country’s economy, certainly at the level of individual materials.

In this study we have therefore combined weight data on material flows with environmental data from Life Cycle Analyses, yielding an indicator we have termed Environmentally-weighted Material Consumption, or EMC. This indicator allows the life cycle environmental impact - 'from cradle to grave' - to be measured as it varies over time as a result of changes in the scale and composition of materials consumption. This aligns the indicator with the intended purpose of an economy-wide material flow policy. The fact that it is the environmental impact of materials rather than their weight that now forms the basic point of departure we see as a major improvement over the indicators proposed to date in the international literature.

The main areas of policy leverage for the EMC presented here are dematerialisation and materials substitution, including use of recycled and reused materials to the extent that is environmental beneficial. Our indicator provides a very satisfactory means of measuring changes on these specific counts and can even be used at company level to assess whether switching to a particular alternative material will reduce or increase overall environmental impact.

The policy analysis undertaken in this study shows that there is also scope for policy that augments materials policy with strategies on dematerialisation and materials substitution. Much of today's materials policy can in fact be termed waste policy, geared to reducing environmental impacts during the final waste phase of the product life cycle by means of recycling. As a result, key strategies further up the supply chain are ignored. A more comprehensive, economy-wide material flow policy would allow the various policy areas to be better attuned to one another and possibly provide an integrated framework for policy analyses. It would moreover create new scope for structural incentives for dematerialisation and more environmentally benign forms of materials usage (as measured from cradle to grave). Overall, then, the approach elaborated here appears to provide an important complement to existing materials flow policy.

In addition, this indicator can be used to establish what materials appear to be contributing most to the various forms of environmental impact (global warming, eutrophication and so on). A materials flow policy geared to these materials would yield the greatest environmental gains and would certainly be more focused than an across-the-board policy keyed to total tonnage throughput. Life Cycle Analysis (LCA) of individual materials going all the way up the supply chain can help identify the reasons why a particular material is environmentally damaging and opportunities for improving its overall environmental profile. Such information may also be useful to industries wishing to excel in terms of the eco-profile of the materials they produce.

How exactly a policy geared to the environmental impact of materials consumption can best be implemented is an issue requiring separate discussion. One option would be to tie an economy-wide materials flow policy into the 2nd Long-Term Energy Efficiency Programme (MJA-II), giving resource-consuming industries the additional option of securing their energy conservation targets by means of life cycle materials policy, and vice versa. These and other options will need to be duly examined if and when it is decided to move ahead on elaboration of an economy-wide material flow policy.

Detailed summary

Background and goal of this study

Materials form the interface between the environment and the economy. They are a *sine qua non* for human prosperity, but at the same time their use gives rise to a wide range of environmental impacts, from resource extraction through to final waste disposal.

In academic circles, cutting back the amount of materials flowing through the economy has long been advocated as a means of reducing the environmental impact of our economic activity. In recent years this position has come to be heard increasingly in policy circles, too. In both the Netherlands (4th National Environmental Policy Plan, NEPP4) and the European Union (Natural Resources Strategy) plans have been announced that are to culminate in the next few years in policy initiatives to regulate the management and use of natural resources to a greater or lesser extent. This kind of policy is referred to as an economy-wide material flow policy: 'material flow policy' because it is the flows of materials (including natural resources and other raw materials) that are to be regulated and 'economy-wide' because it is the economy as a whole that is to be addressed rather than specific production processes or industries.

According to both NEPP4 and the EU, the goal of an economy-wide material flow policy is to reduce the environmental impact of materials consumption. Nonetheless, it is still anything but clear exactly how such a policy is to be shaped. After all, 'materials consumption' ramifies into a wide range of environmental policy areas and overlaps or conflicts with standing policy are by no means inconceivable. There are those who hold that an economy-wide material flow policy should comprise no new policy at all, but merely serve to signal whether overall environmental policy is proceeding in the right direction. Others consider that new policy may be useful in areas not addressed by existing policy, or only inadequately so.

There is also a lack of clarity about how exactly an economy-wide material flow policy is to be monitored. In the Netherlands, the aforementioned VBTB guidelines lay down criteria for the 'monitorability' of policy objectives, begging the question: what is a suitable indicator for monitoring progress on an economy-wide material flow policy? Obviously, the answer to this question will depend on the precise purpose of such a policy.

This study has been carried out in order to establish what leverage can be provided by economy-wide material flow policies within the wider context of environmental policy. In doing so, we have considered how a dedicated materials policy might be woven into standing environmental policy in such a way as to supplement the latter in a meaningful way. It is on the basis of that analysis that a policy goal has been articulated for an economy-wide material flow policy. The final element of the study was to develop an indicator with which to monitor progress towards that goal and compare it with other indicators proposed in the international literature.

In this study we have assumed there is a high likelihood of concrete economy-wide material flow policies of one shape or another being established in the near future. After all, it is not only in the 4th National Environmental Policy Plan that the issue has been raised. Similar plans are also under discussion at the EU and the OECD, and such initiatives are very likely to have consequences for the Netherlands. Precisely because all these plans are currently in the development phase, the results of this study can also be used the bring influence to bear on the international policy-making process.

The results of this study provide a basis for designing a material flow policy, with associated indicators, that is fully in line with NEPP4 and the express wishes of the Dutch Parliament. What our study does not do, however, is examine what policy instruments might be used to articulate such a policy or the legislative framework in which to ground it. These issues would need to be examined in a follow-up study.

Aim of an economy-wide material flow policy

Why the need for a material flow policy? Examination of the relevant policy documents (NEPP4 and the EU's Communication on the Natural Resources Strategy) and the literature on material flow analysis points to there being two main reasons why policy to reduce the magnitude of material flows is held to be desirable:

1. Materials extraction, production, use and waste are inevitably associated with a whole gamut of environmental problems, varying from climate change, acidification and dispersion of toxic substances through to loss of biodiversity. Depletion of renewable, living resources like timber and fish is also a serious environmental issue. Cutting back material flows can therefore help enhance environmental quality across the board.
2. The economic activities of production and consumption in the developed nations have unintended environmental repercussions in the developing world. While industries in the developed world must today meet stringent environmental standards, acquisition of raw materials from further afield is subject to virtually no such conditions. Over the past four decades, there has been a major transfer of polluting 'upstream' activities such as mining to the developing countries, which are often wrecking their own environment for the sake of our prosperity. These environmental impacts, which are not currently accounted for in product prices, can be addressed by an economy-wide material flow policy.

These two reasons can be interwoven to yield the following general objective for an economy-wide material flow policy:

The aim of an economy-wide material flow policy is to reduce the cradle-to-grave environmental impact of natural resource use, irrespective of where that impact occurs.

In policy terms this goal has four basic elements:

- The policy objective is to reduce the environmental burden: this is in accordance with the fact that in the Netherlands, the EU and the OECD the notion of an economy-wide material flow policy originated within environment ministries or working groups with a mandate to improve environmental quality. On this point there is therefore little controversy, it being specifically cited in NEPP4 as well as the EU Communication.
- The steering variable is use of natural resources, encompassing, in the widest definition, all biotic and abiotic materials and energy consumed in the economy.
- The scope of the policy is environmental impact from cradle to grave, and not just impacts in the extraction or waste phase; the policy must adequately address a wide range of environmental impacts associated with the use of natural resources.
- The rider that environmental impact is to be reduced irrespective of where it occurs is in line with one of the cited objectives of an economy-wide material flow policy: to reduce the impact of our production and consumption in other countries.

One final issue requiring discussion is whether the aim of such a policy is to reduce the environmental impact of materials consumption in absolute or relative terms (one possible relative yardstick being environmental impact per unit GDP). Here, we make no pronouncement on this issue, as it requires a prior political decision on the *stringency* of the goals of a materials policy. References below to reducing the environmental impact of materials use do not therefore necessarily translate to an absolute reduction.

Status of an economy-wide material flow policy in the wider policy context
Another important issue is what status an economy-wide material flow policy is to be accorded in the wider environmental policy context. After all, there are already plenty of environmental policies dealing either implicitly or explicitly with materials. In line with the thinking of NEPP4, which states that an economy-wide material flow policy should serve mainly to supplement existing policy, in an earlier study the following boundary conditions were therefore formulated:

- Emissions occurring during materials production are already adequately regulated by standing policies, *viz.* IPPC, various emission trading schemes and regional or local environmental policy. There therefore seems to be little sense in including these emissions in the scope of a new policy on material flows, as this would likely lead to duplication of policy effort.

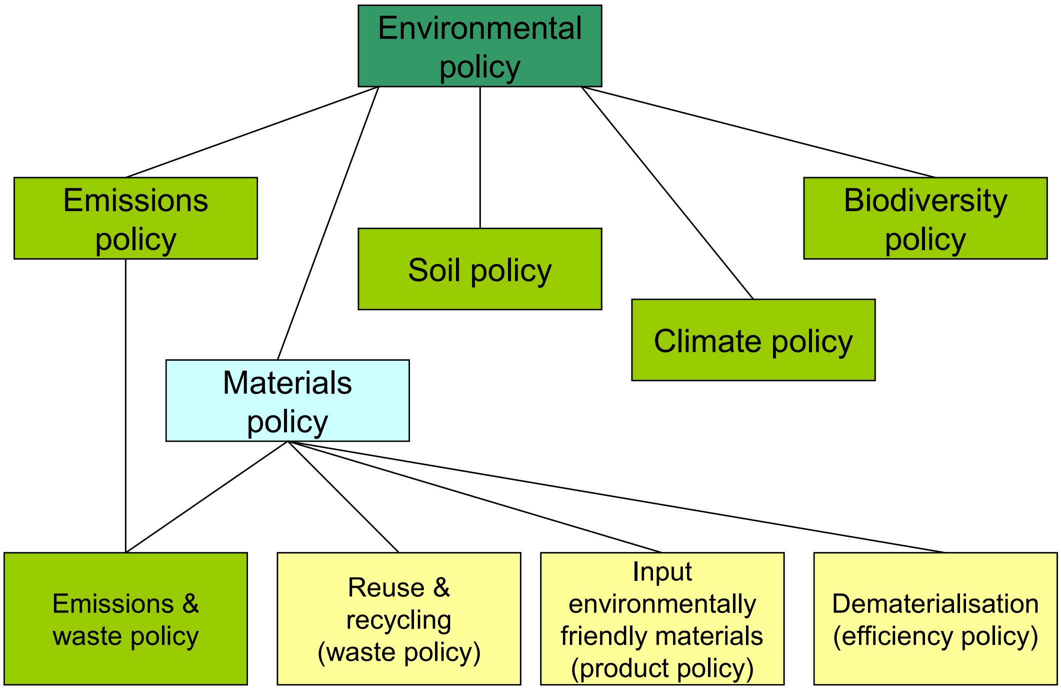
- Natural resources already adequately addressed by standing policy should likewise be excluded from a new material flow policy. Because energy policy has already been satisfactorily elaborated, there would seem little point in criss-crossing it with new policy geared specifically to materials. For this and other reasons, it is proposed to exclude fossil fuels from a material flow policy.

A new material flow policy should therefore be geared above all to the actual use of materials (rather than the emissions associated with their production). Such a policy can be constructed around three main pillars:
- Dematerialisation, i.e. reducing the amount of materials used per functional unit of a product or service, possibly by increasing product lifetime.
- Materials substitution, i.e. replacing environmentally damaging materials with more benign alternatives.
- Reuse and recycling, i.e. increasing use of secondary materials where this helps reduce environmental impact.

It is important to note that reducing the magnitude of material flows - dematerialisation - is here viewed as just one of the possible strategies that might be employed in an economy-wide material flow policy.

The role of a materials policy can therefore be represented as in figure 1.

figure 1 Status of material flow policy in the broader environmental policy context



This also shows that an economy-wide material flow policy can serve to integrate several existing policy areas and bring coherence to waste policy, product policy and (yet to be developed) dematerialisation policy.

How does such policy relate to current policies?
In this study we examined the scope of existing Dutch policies impinging on materials consumption, to assess the extent to which materials substitution, reuse/recycling and dematerialisation are already incorporated in the existing policy framework (Chapter 5). This is crucial for establishing whether the key aim of economy-wide material flow policy is to supplement existing policy or, alternatively, mainly to achieve integration of that policy.

The kind of 'existing policy' we need to consider must first be delineated, for in principle every single environmental policy addresses materials use at least indirectly. Thus, greenhouse gas emissions policy will eventually have an indirect effect on the relative price of materials requiring excessive energy inputs for recovery or processing. As the impact of this kind of policy is almost impossible to estimate, however, it has not been included for consideration in this study.

In the Netherlands there are currently three kinds of policy that do directly address materials and materials use: raw materials policy, sectoral policy and product policy. At present there are very few if any policies on specific materials, in the form of raw materials policy, for example (the FSC label for sustainably produced timber is an exception here). Product policy comprises a wide variety of minor policy initiatives ('product-based environmental care' (PMZ), Integrated Product Policy (IPP), Design for the Environment (DE), environmental labelling schemes and so on), most of which are voluntary in nature. The vast majority of policies addressing products and sectors focuses on the waste phase, however. It is therefore waste policy (National Waste Management programme, 2nd Packaging Agreement) that currently has the greatest impact on materials use and consumption.

At present, the only policy instruments having any clear potential impact on dematerialisation and materials substitution are Vehicle Circulation Tax (VCT) and the 2nd Long-Term Energy Efficiency Programme (MJA-II). It should be noted, though, that the dematerialisation impact of MJA-II will probably be fairly limited for the time being at any rate. It is also worth remarking here that VCT and MJA-II are geared to reducing road wear and energy use, respectively, but not to reducing materials use. What we have here, then, are largely unintended side-effects.

There is some policy in place aimed at rendering material flows sustainable, termed 'profile substitution' in this report[1]. It is at the level of materials that efforts are for example being made to ensure the wood used in the Netherlands is sustainably produced and that use of biotic resources is being encouraged in the chemical industry. At the product level, there are certification and other labelling schemes. However, these impinge mainly on issues of sustainability as such (i.e.

1 This is beyond the scope of the present survey, however.

environmental impact) with little or no effect on dematerialisation or substitution. The Dutch *Milieukeur* certificate in fact lacks any explicit criteria for product recyclability (in contrast to that of the packaging), apart from a handful of products that must themselves be manufactured using secondary materials.
Summarising, it can be concluded that in the Netherlands there is currently no overall vision integrating all the various varieties of materials policy. In the case of waste policy, for example, there is little integration with decisions on product design and engineering, areas offering major scope for dematerialisation and materials substitution, which can in turn influence the magnitude and composition of waste flows. A new form of material flow policy has much to offer in this respect, by explicitly including such options as means of reducing the environmental impact associated with materials use.

An indicator for an economy-wide material flow policy
An indicator must properly match the policy target for which it is designed. Having established in this study that the principal aim of an economy-wide material flow policy is to reduce the environmental burden due to materials use, the obvious way forward is therefore to combine data on consumed quantities of materials with data on the environmental aspects of those materials. In this way it can be determined whether dematerialisation indeed yields environmental gains and whether it makes sense to substitute one material for another.

The indicator constructed for this purpose we have termed Environmentally weighted Material Consumption, or EMC, defined as follows:

EMC = Materials consumption * Environmental impact per material.

Material-specific environmental impacts can be retrieved from existing LCA-databases. In this study we used the ETH database, dating from 1996, which was the most up-to-date and complete LCA database when we embarked on the present study (an update has meanwhile been launched).

Before such an indicator can be elaborated, a number of choices must be made:
1 At what point in the life cycle or supply chain is material consumption to be measured?
2 What materials are to be included in the analysis?
3 What environmental impacts are to be included?
4 How are these environmental impacts to be aggregated?

Although our analysis encompasses environmental impacts ‘from cradle to grave’, it is crucial to first establish where exactly material consumption is to be measured. Is this to be the raw materials level (iron ore, for example), the level of finished materials (iron or steel, say) or some ‘final’ level (products and/or waste)? In this study we have opted for the finished materials level, for two reasons:

1 The consumption of finished materials is driven almost entirely by the manufacturing and construction industries. These have a major influence on the choice of materials used in their products and are therefore a logical choice of target group for policy-makers. If the environmental impact of materials consumption is to be reduced by means of dematerialisation or materials substitution, it is these target groups that will have to do it.
2 It is at this level that most data are available.

In this study we have opted not to include all materials in our analysis but focus on a selection. This restriction of scope was motivated mainly by practical considerations, given the excessive amount of time that would be required to obtain consumption data on several key groups of materials for which Netherlands Statistics (CBS) currently maintains no records.

The approach adopted in this study was first to rank all the materials for which data were available on the basis of their EMC in a certain year and then to take the twenty most environmentally damaging of these to chart trends in EMC between 1990 and 2000. This analysis, the results of which are presented in Chapter 3, identifies the following materials as having the greatest environmental impact:

1 *Food-related materials:* Animal fats; Animal proteins; Fish proteins; Starch crops; Oil crops; Protein crops; Fibre crops for food.
2 *Materials sensu stricto:* Iron and steel; Aluminium (1% and 100% recycled); Copper; Zinc; Lead; Nickel; Sand; Concrete; Cement; Brick; Glass; Paper and board; Plastics (incl. rubber); Animal fibres.

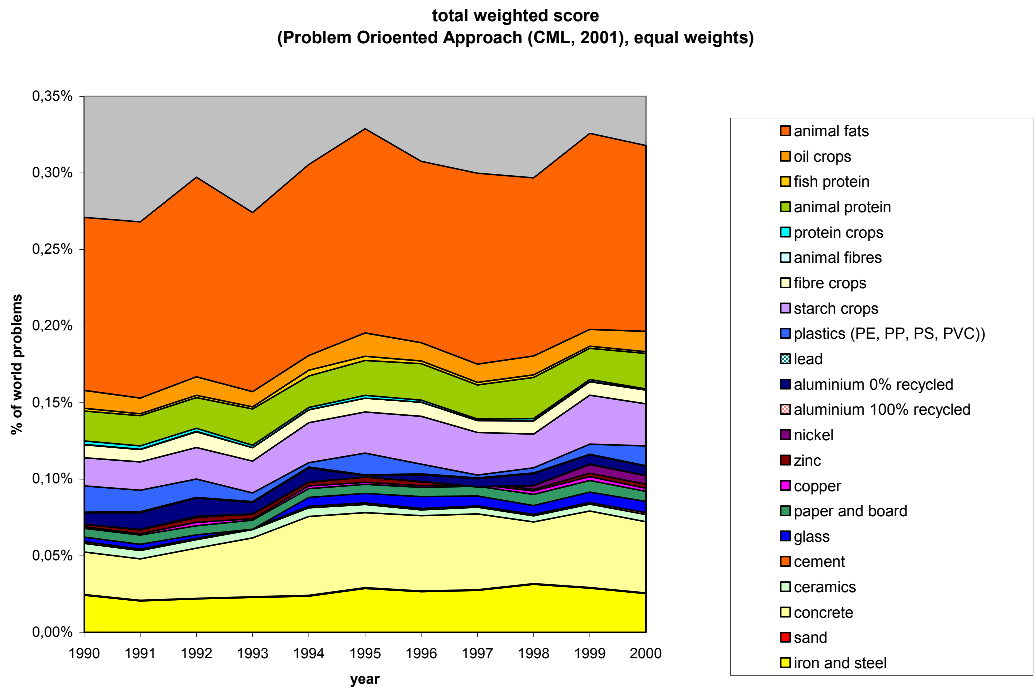
In our estimate, these 21 materials together cover over 90% of the (global) environmental impact of materials usage in the Netherlands.

We have kept our choice of environmental impacts fairly simple, opting to work with the twelve impact categories included in the last complete LCA database: Abiotic resource depletion, Land competition, Global warming, Ozone layer depletion, Human toxicity, Ecotoxicity (the average of Freshwater toxicity and Terrestrial ecotoxicity), Photochemical oxidant formation ('smog'), Acidification, Eutrophication, Ionising radiation and Final solid waste. This choice is obviously debatable. It may well be queried, for instance, whether Abiotic resource depletion is indeed an 'environmental' problem or in fact an economic one. Even though we ourselves see 'depletion' of steel, coal or cement as an economic rather than environmental issue, in this study we have chosen to include Abiotic resource depletion in array of environmental themes, as this meant our analysis could take in the entire data set provided by the LCA database.

A final choice in constructing the EMC indicator concerns the comparative standing of these impact categories. In other words, what counts for more: Global warming or Land competition? For the purposes of this study we opted to leave this question unanswered, giving equal weight to all impact categories in assembling the overall indicator. We do discuss a number of alternative weighting methods, however.

Using the methodology proposed in this report we calculated the Environmentally-weighted Material Consumption, EMC, of the Dutch economy, defined as the cradle-to-grave environmental impact associated with aggregate materials consumption. As figure 2 shows, this indicator rose by 17% in all between 1990 and 2000. As economic output grew by 33% over the same period, a certain amount of 'decoupling' indeed occurred. This 17% rise is also less than the growth of the physical economy, i.e. tonnage growth of the 21 environmentally most damaging materials. The conclusion must be that volume growth of the most polluting materials was below the average growth of all 21 materials.

figure 2 Trends in EMC in the Netherlands for the 21 most environmentally damaging materials, 1990-2000



Running through the individual materials, the contribution of animal fats, concrete and iron and steel to the overall picture is striking. Another noteworthy feature is the relatively high score of agricultural crops across the spectrum of impacts. In fact, two-thirds of the overall score is attributable to consumption of agricultural 'materials'. Above all, it is intensive animal husbandry that proves to have a major environmental impact. Because the processes of materials substitution and dematerialisation are fundamentally different for agricultural products as opposed to construction and industry, we recommend creating two separate indicators: one for agricultural products, and one for other materials, which could then be usefully put to work in two distinct policy settings.

The EMC developed here does not measure the actual environmental impact of present-day materials consumption, for that consumption has been weighted according to the impact categories from the LCA database. This means that implementation of more benign processes at materials-producing industries is not immediately reflected in the indicator, but only after a lapse, when the database is updated. Past experience shows that updates are to be expected every five to ten years. The materials-related environmental impact can then be adjusted to accommodate the state of the art and recalculated. In this sense the indicator is akin to the inflation index used by CBS, which is also periodically adjusted to reflect changes in household spending on the CBS 'basket of goods'. This need not detract from the usefulness of the indicator for policy purposes, however, because it is dematerialisation and materials substitution that such policy is principally addressing, rather than a reduction of the environmental impact of materials-producing industries via end-of-the-pipe or process-integrated measures, which are already sufficiently well covered by standing environmental policies.

Relation to existing indicators

Eurostat has already proposed a number of indicators that aggregate data from material flow analyses to provide an indication of the total quantity of materials flowing through an economy. The following two indicators are most frequently recommended:

- *Direct Material Input: total material input to the economy, whether in the form of extracted materials or imports.*
- *Direct Material Consumption: total material input to the economy, whether extractions or imports, minus total material output from the economy in the form of exports.*

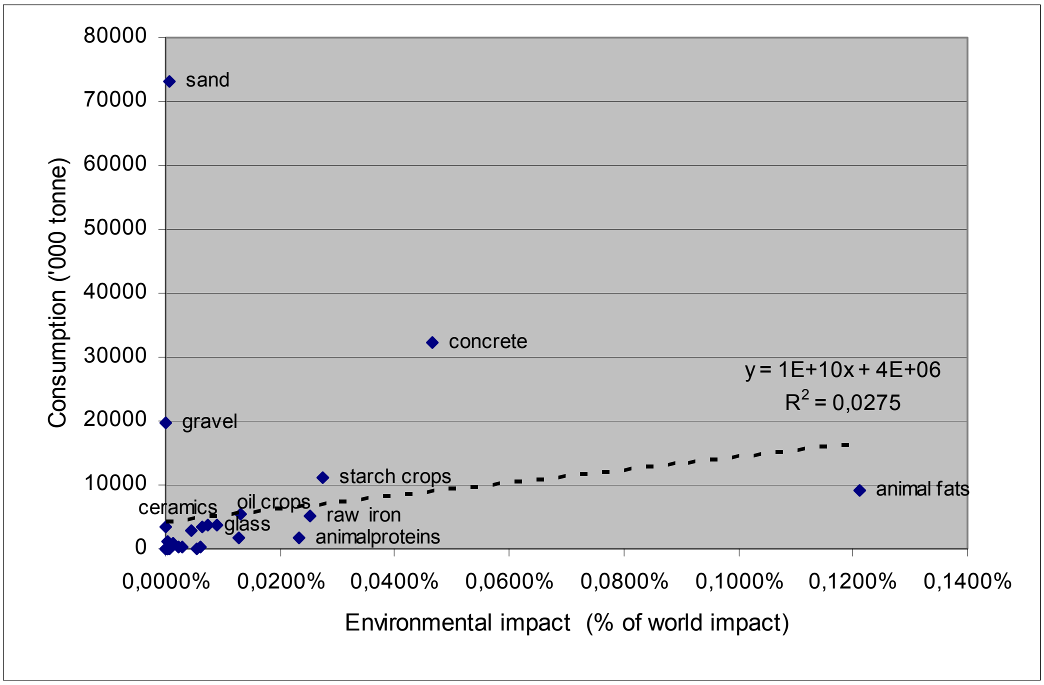
In both indicators all material flows are aggregated on the basis of weight.

A key question now is how these indicators relate to the EMC developed here.

The first thing to be said is that there appears to be no direct relationship between material tonnage and environmental impact. In figure 3 Dutch volume consumption of selected materials in 2000 is shown on the y-axis and environmental impact on the x-axis, calculated as the EMC of the volume consumption of that material.

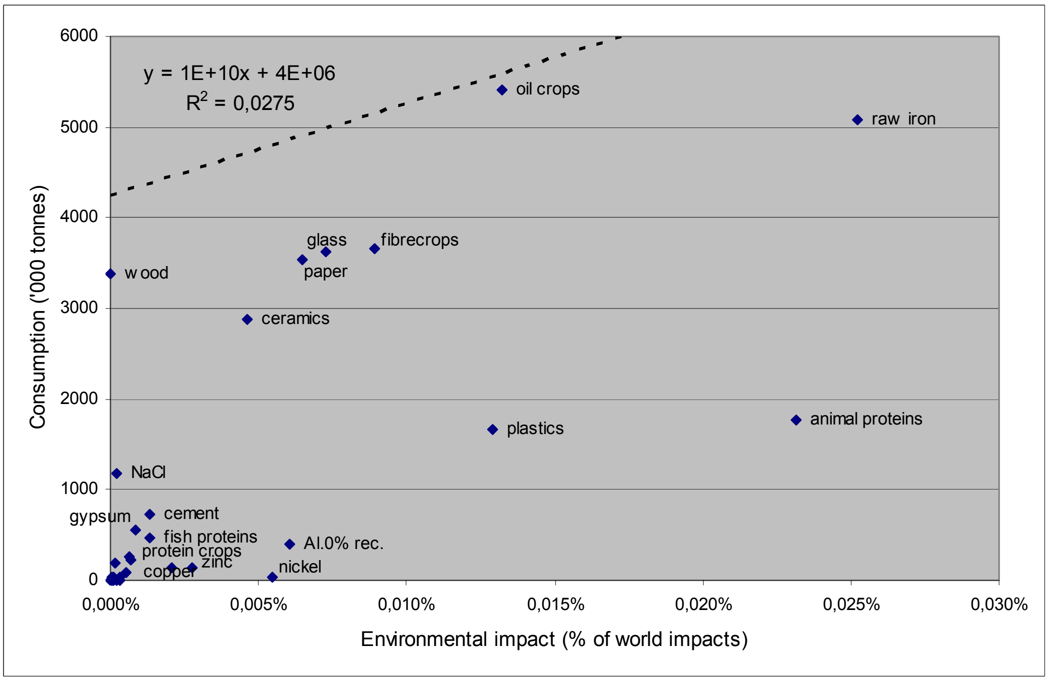
As can be seen in the figure, sand and animal fats occupy the two most extreme positions on the spectrum: sand is extremely bulky, with extraction relatively benign, while animal fats are associated with substantial environmental impacts but relatively light-weight. Simple regression analysis shows that there is no correlation between weight and environmental impact.

figure 3 Relationship between kilogram consumption and cradle-to-grave environmental impact for 34 materials; Dutch data for the year 2000



Zooming in to the bottom left corner of the graph where most materials are plotted, we still see absolutely no relationship between weight and environmental impact (figure 4).

figure 4 Relationship between kilogram consumption and cradle-to-grave environmental impact for 29 materials; Dutch data for the year 2000



Here is clear evidence that weight is a poor yardstick for the environmental burden associated with the use of individual materials. This raises serious doubts about the indicators currently proposed by Eurostat and the OECD, which measure material flows precisely on a weight basis. Such indicators bear little if any relationship to the associated environmental problems, the tackling of which was precisely the motive for developing an economy-wide material flow policy in the first place. To our mind, then, these indicators must be rejected as a means of monitoring progress on such a policy and articulating it in measures for individual target groups.

The indicators currently being discussed and considered for implementation should therefore be revised or preferably replaced by indicators that do match the policy objective of an economy-wide material flow policy. The Environmentally-weighted Material Consumption, EMC, developed in the present study can provide a better starting point for an alternative indicator.

1 Introduction

1.1 Background

It is common knowledge that materials use is often associated with a host of environmental problems. After all, given the impossibility of limitless recycling, all the materials flowing into an economy will inevitably leave it sooner or later as wastes or emissions. A rough-and-ready estimate indicates that materials consumption is responsible for at least 20% and possibly as much as 99% of today's most pressing environmental problems such as global warming, acidification, final waste production, ozone layer depletion, human toxicity and ecotoxicity [Van der Voet *et al.,* 2003].

For this and other reasons there is growing interest in establishing some form of 'economy-wide material flow policy', i.e. policy addressing the overall flows of materials through the economy. The underlying notion is that while environmental policies geared to materials are already implicitly in place in several realms of environmental policy-making (waste or product policy, for example), an integrated strategy on materials and natural resources is still sorely lacking. In recent years a number of countries and international forums have taken initiatives to establish this kind of 'economy-wide' material flow policy. Many studies have also been funded to research the scope for developing indicators for such a policy[2].

The present study is concerned with the issue of how an economy-wide material flow policy might be shaped in the Netherlands and, in particular, how such a policy might be monitored by means of suitable indicators. In doing so, we also review international developments in this field, assessing the extent to which the options presented here tie in with those developments.

During the course of this project, the international community has not stood still on the issue of economy-wide material flow policy. This report therefore also endeavours to provide an up-to-date review of developments in this area, insofar as these have occurred in forums of relevance to the Dutch policy context, such as the OECD and EU.

1.2 Dutch policy developments

In the Netherlands' 4th National Environmental Policy Plan (NEPP4) the government announced its intention to elaborate a policy on 'dematerialisation'. Such policy is seen mainly as a means of supplementing existing environmental policy: according to NEPP4, policy geared to reducing specific forms of environmental impact is more effective, and generally makes more economic sense, than reducing the overall flow of materials as such. Dematerialisation, i.e. reducing material flows, is therefore regarded as an additional environmental

[2] For the Netherlands, see for example [Ter Riele *et al*., 2001], [Dijkema *et al*., 2003] and [Van der Voet *et al*., 2003].

policy strategy (see Appendix C for a summary of the ideas on dematerialisation set out in NEPP4).

The contours of a dematerialisation policy in line with the vision of NEPP4 have been set out in an earlier study carried out for the Dutch environment ministry VROM [De Bruyn *et al.*, 2003]. Among the recommendations of that study were the following:

- Kilograms of materials are a poor yardstick for measuring the environmental impact of material flows. In order to effectively monitor material flows and reduce their environmental impact, environmentally related indicators need to be developed. The scope for developing such indicators has been investigated by [De Bruyn *et al.*, 2003] and, more specifically, by [Van der Voet *et al.*, 2003].
- A material flow policy should encompass more than merely dematerialisation (i.e. reducing materials tonnage), environmentally benign material substitution being potentially at least as important. Weighting material flows according to their environmental impact provides a means of ensuring that gains in one area (more dematerialisation) are not at the expense of losses in another (substitution of relatively benign materials for lighter but more polluting ones).
- Raw materials already adequately addressed by existing policies should not be included in the scope of this kind of materials policy. As an energy policy has already been satisfactorily elaborated in the Netherlands, there would seem to be little point in criss-crossing it with a new policy specifically on materials. For this and other reasons, it is recommended to exclude fossil fuels from a material flow policy.
- Materials savings and environmentally benign materials substitution appear to play only a subsidiary role in today's environmental policies. Materials savings could therefore form a rationale for environmental policy in much the same way as energy saving in the context of energy policy.

The topic of dematerialisation has not re-emerged as a debating issue in the Dutch parliament in recent years. Neither is the notion mentioned in the new government's memorandum outlining its environmental policy, entitled 'Fixed values, new forms'.

1.3 International policy developments

Since the early 1990's a number of initiatives have been taken in various European countries to articulate an analysis of the physical side of the economy. Building on ideas proposed by Ayres and Kneese (1969) regarding interlinkages between the monetary and physical dimensions of the economy, a series of attempts have been made to arrive at a properly balanced system of Material Flow Accounts (MFAs) encapsulating the physical dimension of the economy[3].

Based on such MFAs, indicators have been developed that are designed to describe the extent to which there are changes over time or inter-country

3 See [Adriaanse *et al.*, 1997; Matthews *et al.*,2002; Eurostat, 2002]. Note that the abbreviation MFA is also used for Material Flow *Analysis*.

differences in the total weight of aggregated material flows through the economy or economies in question [Adriaanse *et al*., 1997; Matthews *et al*., 2002]. The procedure for calculating such indicators has been described by Eurostat in a *Methodological Guideline* and Eurostat has already published its first quantitative survey of material flows in the EU15 [Eurostat 2001, 2002].

Although it is difficult to establish whether these research results and data sets have played a part in international policy development, it is a fact that in various EU countries and within the EU itself as well as the OECD many initiatives have meanwhile been taken to develop some form of economy-wide material flow policy.

In its 6th Environmental Action Programme the European Union announced its intention to instigate a policy on dematerialisation and resource productivity and in this connection the European Commission in late 2003 published a *Communication* outlining a Thematic Strategy on the Sustainable Use of Natural Resources [EC, 2003]. This document (summarised in Appendix B) places great emphasis on the notion that it is the environmental burden associated with resource use that must be reduced rather than materials use as such. How this goal is to be achieved is not indicated in the Strategy, but is to be elaborated in the course of 2004 and 2005. The Communication makes it unlikely that the indicators developed by Eurostat will be used to articulate dematerialisation policy, unless it can be established that these indicators are a good proxy for the environmental impact of materials use. On this issue, opinions are divided[4].

The OECD, by way of its Working Group on Environmental Indicators, recently published *Recommendations* [OECD, 2004] calling on countries to monitor their material flows[5]. The following Recommendations (for full text, see Appendix A) are particularly relevant here:

- That countries take steps to improve information on material flows, develop methodologies to compare material flows over time and among countries, and develop tools to measure resource productivity.
- That indicators be developed that draw on earlier work.

Although not explicitly stated, ‘earlier work’ is probably a reference to the framework developed by Eurostat. The Recommendations are to be worked up further in the OECD between 2004 and 2006, the aim being to establish a definitive set of Recommendations and methods embodying realisation of the original recommendations.

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4 Advocates of this approach [Ayres & Schmidt-Bleek, 1993; Hinterberger *et al*., 2003] claim that from a practical perspective weight is the best available yardstick for pollution-related environmental impacts. Opponents [De Bruyn *et al*., 2003; Van der Voet *et al*., 2003 and others] have demonstrated that there is at any rate little if any correlation between the weight of materials and their impact as computed in LCAs. To date, there has been no research to establish the extent to which the Eurostat weight indicators correlate with a country’s CO_2 emissions, for example, one reason being that CO_2 emissions and MFAs differ in their system boundaries.

5 Although the Recommendations (some eight of which have been published on environmental indicators since 1979) are formally indeed merely recommendations, with no legal obligation for countries to adopt them, there may well be pressure to do so.

1.4 Research goal and report structure

The present study seeks to elaborate a possible material flow policy for the Netherlands and assess how it differs from the approaches proposed in the international literature.

More specifically, the research sought to answer the following specific question:

Is it possible and desirable to design an element of a material flow policy revolving around improved resource productivity that satisfies the requirements for a dematerialisation policy stipulated in the 4th National Environmental Policy Plan (NEPP4) and that can be used to stimulate an international debate on elaboration of a policy on sustainable management of natural resources and resource productivity?

In this description of our goal, three notions are pivotal:
- *Material flow policy*, here defined as policy geared to reducing the environmental impact associated with the extraction, production, use and final waste phase of materials. Examples include Integrated Product Policy (IPP), waste policy, recycling policy and Design for the Environment (DE), all of which focus specifically on materials.
- *Increasing materials productivity* is here taken to mean reducing cradle-to-grave environmental impact through wise use of resources and materials and eco-friendly materials substitution. Although this is very much in line with the well-known 'Factor 4' and 'Factor 10' initiatives [von Weiszacker *et al*., 1997; Factor 10 Club, 1994], our concept proceeds from materials-specific environmental impact rather than simple kilogram consumption.
- *NEPP4 requirements*: in line with our earlier work [CE, 2003] we take it here that NEPP4 sets two key requirements as to how a dematerialisation policy is to be elaborated: (1) the policy must reduce the environmental burden due to the extraction, production, use and final waste phase of materials, and (2) it must supplement, rather than interweave, existing policy.

To answer the research question satisfactorily, the project will have to achieve three things:
1 Develop an indicator to measure materials productivity, as defined above.
2 Identify any 'gaps' in current materials-related policy where dematerialisation (i.e. greater materials productivity) might play a key role.
3 Establish a communications strategy with parties in the EU or OECD to actively steer the debate, assess the scope for creating coalitions and prevent an indicator based on kilogram inputs of materials to the economy being adopted as an element of EU or OECD policy.

The present document reports on progress on the first two issues and makes some brief recommendations on the third. It is structured as follows: Chapter 2 opens with a broad discussion of the goal of a material flow policy and indicators with which to monitor such a policy, including the various indicators developed internationally over the past few years. This sets the stage for the choices made here in developing an environmentally-weighted indicator in line with the NEPP requirements for a Dutch material flow policy. In Chapter 3 the methodological choices made in building this indicator are discussed, while in Chapter 4 the proposed indicator is fleshed out using empirical data and actual trends examined and discussed. Chapter 5 analyses current Dutch policies addressing materials usage and investigates the extent to which the material flow policy outlined in this study can indeed serve to supplement existing policy efforts. The conclusions of the study are presented in Chapter 6

1.5 Relation with other studies

This study can be seen as a further elaboration of the principles formulated in an earlier CE study carried out for the Dutch environment ministry, VROM, in which the contours of an effective materials flow policy were sketched and potential indicators briefly examined [De Bruyn *et al.*, 2003]. In an earlier phase of its development, the indicator methodology proposed here was recommended in a study undertaken by CML for the Dutch National Institute of Public Health and Environmental Protection, RIVM [Van der Voet *et al*., 2003].

CML has also been collaborating with CE and the Wuppertal Institute to examine the scope for using an environmentally weighted indicator in the context of the EU Resources Strategy [EC, 2003]. The results of this study were recently published in [Van der Voiet *et al*. 2004].

In addition, studies on MFA indicators based on the Eurostat guidelines are currently in progress in a wide variety of countries.

2 From policy to indicators

2.1 Introduction

This chapter examines the notion of an economy-wide material flow policy in more detail and discusses the indicators available to policy-makers to help them set targets for such policy and quantitatively evaluate policy progress.

First, in section 2.2, we describe the constituent elements of such a policy and provide more precise definitions of several key terms. In section 2.3 we examine the indicators already developed for this kind of policy and explore their differences, subsequently presenting proposals for an indicator that captures the environmental impacts of material flows.

2.2 Economy-wide material flow policy

2.2.1 Concepts from the call for satellite accounts

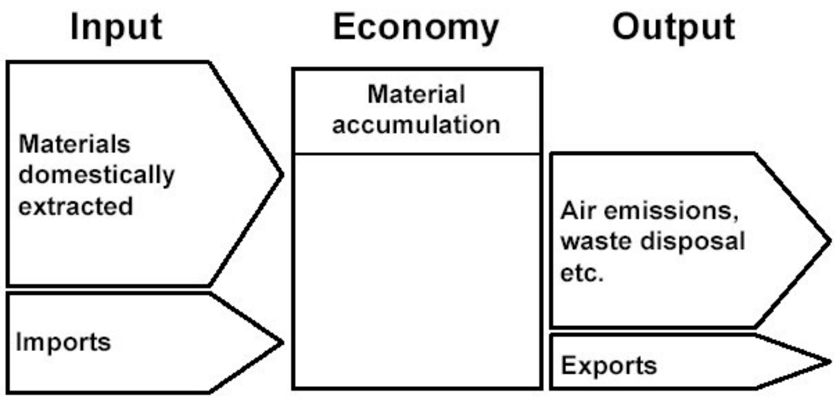
Since the start of the 'second wave' of environmental awareness in the affluent nations in the early 1990's, there have been many calls to augment the standard system of economic statistics and economic indicators with a complementary set of environmental statistics. At the UN Conference on Environment and Development (UNCED) in Rio de Janeiro in 1992 the first steps were taken to establish a system of 'satellite accounts', building on the existing economic System of National Accounts (SNA). The aim is to integrate economic and environmental accounting and provide the economic, monetary data with a physical dimension. According to the UN [UN 2001, p.1] the proposed System of Environmental and Economic Accounts (SEEA) is 'a coherent, comprehensive accounting framework which allows the contribution of the environment to the economy and the impact of the economy on the environment to be measured objectively and consistently'.

Within the SEEA framework, several tools have been developed for describing the physical dimension of the economy:
1 Economy-wide material flow accounts (MFA).
2 The physical input-output table (PIOT).
3 The physical trade balance (PTB).

In [Eurostat, 2001] economy-wide MFAs are described as follows:
'economy-wide material flow accounts and balances show the amounts of physical inputs into an economy, material accumulation in the economy and outputs to other economies or back to nature'.

This is thus a simple input-output analysis, as illustrated in figure 5. The units are weight, so that all the flows distinguished in the figure can be expressed in kilotonnes[6].

figure 5 Economy-wide material flow accounting (source: Eurostat, 2001)



An essential feature here is that the economy itself is taken to be a 'black box'. In other words, no consideration is given to flows *within* the economy, only to what goes in and what comes out. The various MFAs carried out to date differ in the system boundaries used to define national economies and the kinds of materials they include. If air, for example, is also taken as a 'material', then the input of air and output of CO_2 soon come to dominate the overall flow.

To look at what is going in the black box of the economy, a physical input-output table, or PIOT, is a more useful tool. PIOT's provide insight into what happens to flows within an economy and usually distinguish a set of economic sectors, detailing transactions between them[7]. A PIOT is actually very similar to the input-output tables employed in the economic statistics for the National Accounts and in fact forms the most sophisticated analysis tool. Because the flows involved in intersectoral supply chains can obviously not be physically monitored, at the moment the only way to create a PIOT is to use estimates derived from economic input-output tables.

Given the importance of trade flows in economy-wide MFAs, another option is to perform an abbreviated kind of PIOT focusing solely on flows to the national economy from abroad and vice versa (i.e. imports and exports). This is known as a Physical Trade Balance, or PTB.

6 In principle, material flows can also be expressed in terms of volume (see [Moll, 1993]), which is considered a more economic unit, because volume says more about the utility value of a material than weight.

7 PIOT's can also be carried out on individual materials [Hoekstra, 2003].

2.2.2 Policy applications of economy-wide MFAs

Work on developing a methodological framework for calculating physical flows through the economy was started before it had been properly decided what that data was to be used for. Although most people agree that it may well be useful to know where certain environmentally damaging materials originate, what is made from them and what happens to them in the waste phase, it is to be queried whether economy-wide MFAs provide the kind of information that policy-makers need.

This issue has been debated in various contexts For example, the Eurostat guidelines [EUROSTAT, 2001] have a chapter on ‘Policy Demand and Uses of MFA’ (see Box 1). On closer reading, however, this proves to be concerned mainly with analytical exercises to calculate an economy’s *aggregate* use of materials.

Box 1: Policy objectives of economy-wide MFA according to Eurostat (2001)

The main purposes of economy-wide material flow accounts and balances are to:

- provide insights into the structure and change over time of the physical metabolism of economies;
- derive a set of aggregated indicators for resource use, including for the EU-level initiative on Headline Indicators and the United Nations’ initiative on Sustainable Development Indicators;
- derive indicators for resource productivity and eco-efficiency by relating aggregate resource use indicators to GDP and other economic and social indicators;
- provide indicators for the material intensity of lifestyles, by relating aggregate resource use indicators to population size and other demographic indicators;
- through their underlying data structure integrated with the national accounts contribute to organising, structuring and integrating available primary data and ensure their consistency;
- react flexibly and quickly to new policy demands (e.g., related to specific materials) through this data structure which can be adjusted easily and put to additional uses;
- permit analytical uses, including estimation of material flows and land use induced by imports and exports as well as decomposition analyses separating technological, structural and final demand changes.

[Hinterberger *et al.*, 2003] - advocates of MFAs in the policy setting - nonetheless conclude as follows:
‘So far MFA did not contribute sufficiently to political conclusions to be drawn from its results. MFA studies in most cases focused on methodological issues and the presentation of material balances and aggregated indicators. In general, authors did not take a step beyond the presentation of results, to further reflect on possible policy-related uses of results. This applied policy-related evaluation of MFA results should be one central issue for further development of material flow analysis in the future’.

However, the idea seems to have somehow rooted that this is more a question of convincing politicians of the usefulness of MFAs than adjusting MFAs to meet politicians’ needs.

Nevertheless, in the literature - and increasingly in the political realm, too - a number of reasons are implicitly given why there is a need to elaborate some form of economy-wide material flow analysis for use by policy-makers. These can be summarised under three headings:

1 To develop a universal yardstick that adequately captures a broad set of environmental problems.
2 To reduce the impact of our material consumption on other countries.
3 To make the environmental impact associated with materials consumption an explicit policy issue, analogous to energy consumption.

The first angle departs from the observation, first made by economists like Ayres and Kneese (1969) and Herman Daly (1991), that all the materials flowing into an economy will eventually leave it as waste or emissions ("What comes in must go out"). In this approach, it is the actual magnitude of the material flows that is seen as the issue. By reducing these, with other factors unchanged, pollution will decrease, resource depletion become less acute and waste flows be reduced. If we succeed in increasing our resource productivity by a Factor 4 [von Weiszäcker *et al.*, 1997] or Factor 10 (Factor 10 Club), a whole range of added benefits are to be expected, including gains for biodiversity[8].

This approach has naturally come in for wide criticism, above all because the magnitude of material flows (in kilograms) says little about the general environmental impact of those flows, nor about their impact on biodiversity and resource depletion in particular. The question of what exactly is to be reduced if such policy is to serve any purpose has been raised on several occasions (e.g. [Reijnders, 1998]; [De Bruyn *et al.*, 2003]). When it comes to environmental impact, fairly small kilogram flows of relatively toxic materials like heavy metals or radioactive materials may be far more important, although these will be swamped by the far greater weight of flows of construction materials and/or food crops. As NEPP4 states quite rightly, moreover, dedicated policy is often a far more effective and cost-efficient way to secure environmental targets. Reducing the flow of materials across the board in order to address a wide range of environmental problems is probably just as crude an instrument for saving the environment as reducing economic growth - and is likely to meet with the same response from society if it were adopted as government policy.

The second approach often - though not necessarily - overlaps the first. The driving notion here is that the use of materials carries with it a 'rucksack' of environmental impacts arising in their country of origin (compare the 'ecological footprint' of [Wackernagel & Rees, 1996] and the 'rucksack' approach of [Schmidt-Bleek, 1993]). Thus, materials consumption in the Netherlands has ecological consequences in other countries[9]. It is held that this rucksack has become 'heavier' with time as polluting industries and mining operations have

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8 In this perspective there are often several additional motives, such as a conviction that people in the affluent North have too great an 'ecological footprint' and need to reduce their consumption to give the South (and China) an opportunity to achieve greater prosperity without exceeding the Earth's carrying capacity.

9 A Dutch parliament motion adopted in 1999 [Van der Steenhoven *et al.*, 1999] cited this as the main reason why the Dutch government should pursue a policy of dematerialisation.

been transferred to developing countries. Some researchers have suggested that the cuts in pollution in the developed world can be explained largely by such transfers (see for example [Stern *et al.*, 1996]). Although this transfer hypothesis has not yet been adequately validated in empirical studies (see the discussion in De Bruyn, 2000), it may certainly be useful to take a 'cradle-to-grave' approach to environmental policy, with producers and consumers being held responsible for upstream impacts. The Netherlands' 2nd Long-Term Energy Efficiency Programme as well its product policy are based on this kind of life cycle philosophy and these could be provided solid justification with an economy-wide material flow policy.

The third approach posits that while there is already a great deal of policy addressing materials and their environmental impact, what is lacking is a coherent, integrated policy in this area. Thus, policy is currently focused on specific phases of the life cycle (mining policy, product policy and/or waste policy) with no generic policy addressing all phases - in contrast to energy policy, for example. The energy policy setting for the Dutch economy (see the Third Memorandum on Energy [EZ, 1996]) comprises the following goals, for example:
- Greater use of renewable energy resources.
- Use of cleaner (e.g. low-carbon) fossil energy resources.
- Energy conservation and increased energy efficiency.

In analogous fashion, a materials policy could be elaborated pursuing:
- Greater use of renewable resources and recycled materials.
- Use of cleaner materials and environmentally benign materials substitution.
- Materials conservation and increased materials productivity.

Although such initiatives have been taken across a string of policy areas, there is little integration among them. An economy-wide material flow policy could serve as the lynchpin and reference point for all these policy initiatives.

2.2.3 A possible perspective for the Netherlands

After dematerialisation was identified in the 4th National Environmental Policy Plan as a new policy area, in dialogue with the environment ministry, VROM, and the National Institute of Public Health and Environmental Protection, RIVM, a number of studies were carried out to examine how such policy might best be articulated. According to good Dutch custom, this has involved several rounds of consultations with scientists, policy officials and industry representatives.

These studies and consultations have indicated that the third of the philosophies outlined above may tally best with the interests of the various societal actors. By adopting a cradle-to-grave life cycle approach, as in this third approach, a material flow policy can also contribute to achieving the goal of the second: to reduce the environmental burden in other nations arising as a result of Dutch imports.

Because the relationship between kilograms and environmental impact is flimsy at best, there is little support in the Netherlands for a material flow policy geared to weight. There is a clear preference, rather, for a focus on the environmental impacts associated with the materials and the explicit aim of this kind of material flow policy should thus be - in line with both NEPP4 and the EC Communication (COM 572) - to reduce the environmental impact due to the material flows.

Against this background, the purpose of such a policy might then be formulated as follows:

The aim of an economy-wide material flow policy is to reduce the cradle-to-grave environmental impact of natural resource use, irrespective of where that impact occurs.

In policy terms this goal has four basic elements:
- The policy objective is to reduce the environmental burden: this is in accordance with the fact that in the Netherlands, the EU and the OECD the notion of an economy-wide material flow policy originated within environment ministries or working groups with a mandate to improve environmental quality. On this point there is therefore little controversy, it being specifically cited in NEPP4 as well as the EU Communication.
- The steering variable is use of natural resources, encompassing, in the widest definition, all biotic and abiotic materials and energy consumed in the economy.
- The scope of the policy is environmental impact from cradle to grave, and not just impacts in the extraction or waste phase; the policy must adequately address a wide range of environmental impacts associated with the use of natural resources.
- The rider that environmental impact is to be reduced irrespective of where it occurs is in line with one of the cited objectives of an economy-wide material flow policy: to reduce the impact of our production and consumption in other countries.

One final issue requiring discussion is whether the aim of such a policy is to reduce the environmental impact of materials use in absolute or relative terms (one possible relative yardstick being environmental impact per unit GDP). Here, we make no pronouncement on this issue, as it requires a prior political decision on the *stringency* of the goals of a materials policy. References below to reducing the environmental impact of materials use do not therefore necessarily translate to an absolute reduction.

Now the aim of an economy-wide material flow policy has been rendered more specific, it can be discussed how such policy might be articulated within the wider environmental policy context. After all, there are already plenty of environmental policies dealing either implicitly or explicitly with materials and there seems to be little point in cross-tracking these with entirely new policy thinking. In line with the stated perspective of NEPP4 - that economy-wide material flow policy should above all supplement existing policy - in an earlier study the following boundary conditions were therefore formulated (see [De Bruyn *et al*, 2003]):

- Emissions occurring during materials production are already adequately regulated by standing policies, in the form of IPPC, various forms of emissions trading and regional and local environmental policy. There therefore seems to be little sense in including these emissions in the scope of a new policy on material flows, as this would likely lead to duplication of policy effort.
- Natural resources already adequately addressed by standing policy should likewise be excluded from a new material flow policy. Because energy policy has already been satisfactorily elaborated, there would seem little point in criss-crossing it with new policy efforts from resource policies. For this and other reasons, it is proposed to exclude fossil fuels from a material flow policy[10].

A new materials flow policy should therefore be geared above all to the actual use of materials (rather than the emissions associated with their production). Such a policy can be constructed around three main pillars:

- Dematerialisation, i.e. reduction of the amount of materials used per functional unit of a product or service, possibly by increasing product lifetime.
- Materials substitution, i.e. replacement of environmentally damaging materials with more benign alternatives[11].
- Reuse and recycling, i.e. greater use of secondary materials where this helps reduce environmental impact.

It is important to note that reducing the magnitude of material flows - dematerialisation - is viewed as just one of the possible strategies that might be employed in an economy-wide material flow policy.

The role of a materials policy can therefore be represented as in figure 6.

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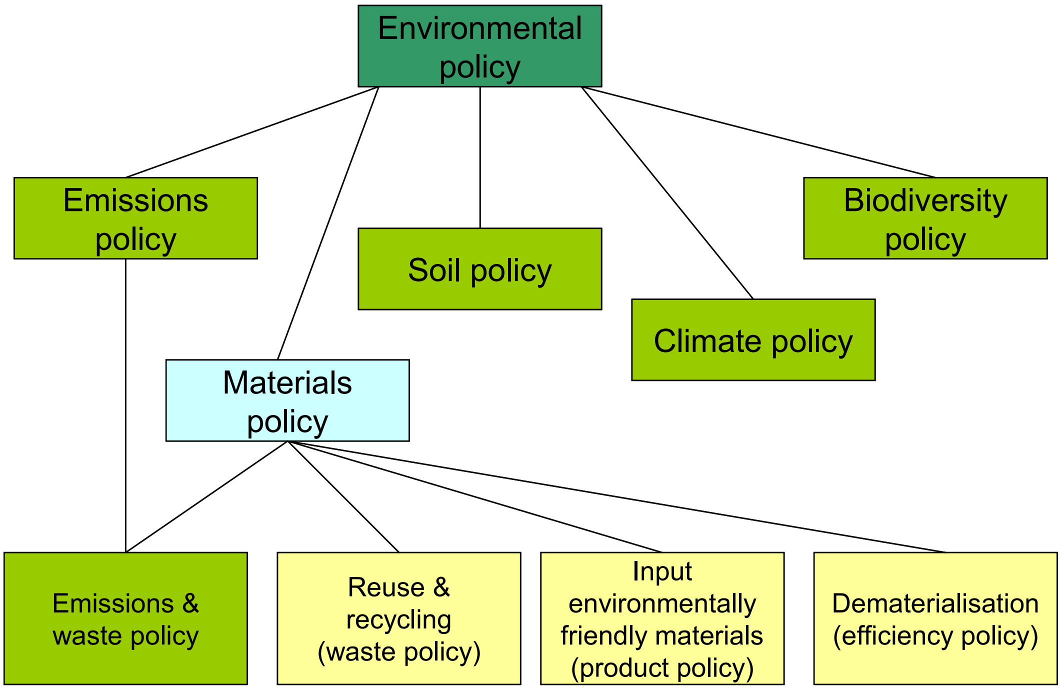
10 This is not to say the two policy realms might not be merged at some later stage.

11 This may also involve substitution within one and the same group of materials ('profile substitution'), as with certified timber being substituted for non-certified timber. On this point, see also Chapter 5.

figure 6 Status of material flow policy in the broader environmental policy context



The first thing to be noted is that a material flow policy is just one element of overall environmental policy, as the former should not attempt to address the entire gamut of environmental issues. Secondly, as the figure shows, an economy-wide material flow policy can serve to integrate several existing policy areas and bring coherence to waste policy, product policy and (yet to be developed) dematerialisation policy.

This perspective has the following advantages:

- It ties in best with NEPP4, which states that dematerialisation/materials policy should above all supplement existing policy.
- It leaves dedicated emissions policy untouched, effective as it is, in line with the stated preference of NEPP4.
- It introduces a life cycle approach to environmental policy on a macro-economic scale, something that is currently lacking.
- It can support other environmental policy, by identifying materials scoring high on a whole range of environmental impacts that might otherwise remain invisible to policy-makers.
- It dovetails with the LCA-like approach often adopted in the Netherlands to fine-tune environmental policies.

How precisely such policy is to be elaborated (with which instruments and in pursuit of what targets) is as yet unclear. However, this outline does provide a possible perspective for articulating a national material flow policy in the Netherlands. Another crucial issue is the kind of indicators to be employed in such a policy, a topic addressed in the following section.

2.3 Indicators for a material flow policy

2.3.1 Indicators in relation to the policy objective

In the policy context, indicators are used to define quantitative targets and monitor policy effectiveness. They also often serve as implicit justification for the policy in question: if a certain indicator points to unwanted developments, policy interventions can be justified with reference to that indicator.

It is therefore important that the indicator properly match the overall objective of the policy concerned, for otherwise no quantitative targets can be set nor progress measured. Besides, policy legitimacy may suffer if there is a mismatch between indicator and target.

The ultimate policy objective is therefore of the essence. The goal of Dutch policy, as summarised above, might therefore be phrased in its most general form as follows:

The goal of an economy-wide material flow policy is to reduce the (relative or absolute) cradle-to-grave environmental impact associated with use of natural resources, regardless of where that impact arises, by means of a change in the magnitude and composition of the natural resources and materials used.

2.3.2 Methodological aspects of an indicator for economy-wide MFAs

To develop an indicator highlighting the environmental impact due to the use of natural resources, two methodological issues must first be resolved:
1 Aggregation: how is the sum total of environmental impacts to be established?
2 System boundaries: what counts as 'use of natural resources' and what does not?

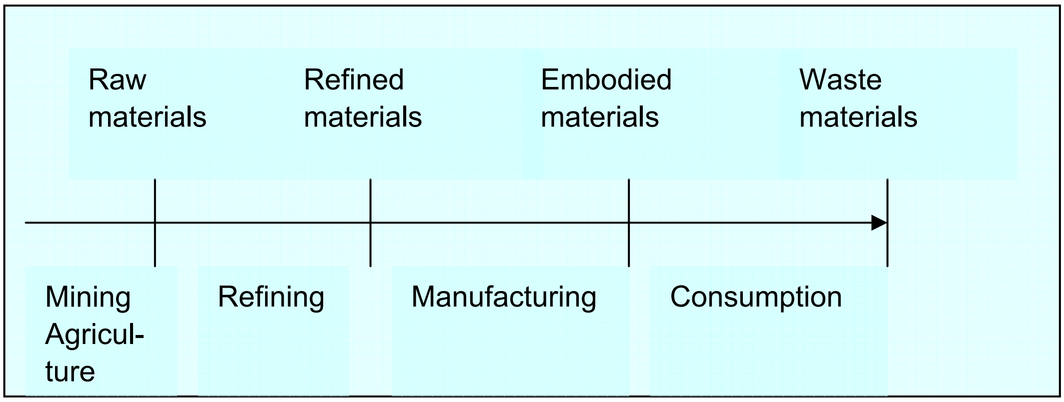
The aggregation issue is in essence a simple one: on what basis do you add up a kilo of aluminium and a kilo of steak? There are, in principle, several options available, including economic value, weight, environmental burden and the energy to produce one kilo of the material. If the aim of an economy-wide material flow policy is to reduce the burden on the environment, then it would seem self-evident that that burden should also form the basis for aggregation.

The issue of system boundaries is concerned with the fact that materials flow through the economy by lengthy and complex routes. In the most general of terms, we can distinguish the following four basic categories of materials:
1 Raw materials and agricultural crops.
2 Refined materials.
3 Embodied materials, i.e. materials embodied in products.
4 Waste materials, arising after needs have been satisfied.

Each of these categories arises in a distinct phase of the economic process, *viz.*:
1 Extraction and harvesting / Mining and agriculture
2 Refining.
3 Manufacturing.
4 Consumption.

The relationship between these four phases and categories of material is illustrated in figure 7.

figure 7 Relationship between phases of economic process and categories of material



The chain from raw materials to waste materials is characterised by an ever larger fraction of the material initially extracted or harvested being converted to waste. As the material is processed further and further, the economically useful fraction grows ever smaller and the waste fraction ever larger. As an obvious example, only a tiny fraction of the bauxite mined actually ends up in the aluminium foil we use in the kitchen. The rest remains behind as waste, together with the energy used in the various phases of the supply chain[12].

This basic scheme is shown schematically in figure 8, in which reuse and recycling have been omitted for simplicity's sake.

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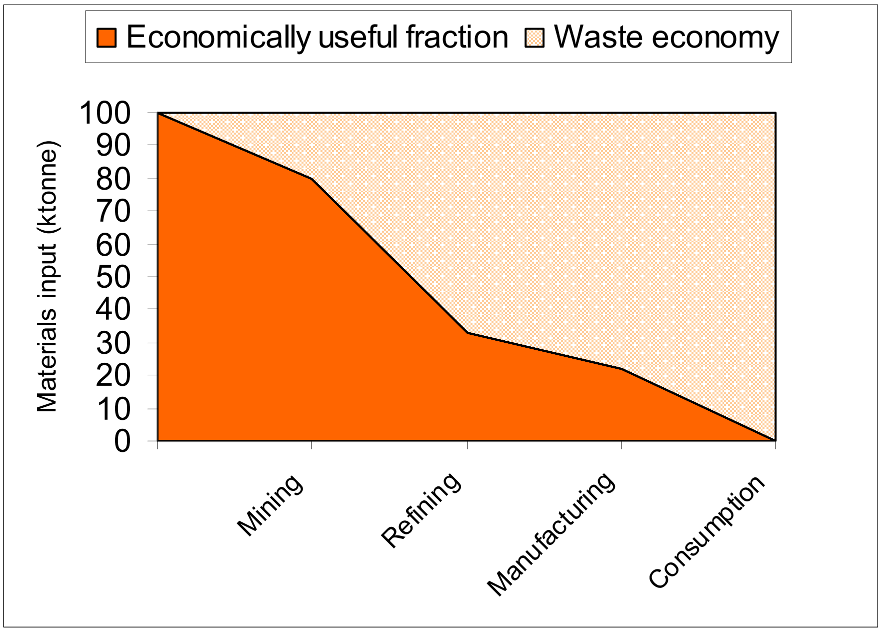
12 Some scientists describe this in terms of the Second Law of Thermodynamics, applied to materials (see e.g. [Young, 1994]). There is certainly logic to this, as each processing phase entails a separation process whereby the material (and the products in which it is embodied) is divided into a useful and a useless fraction, i.e. waste. As with energy, then, one can in fact say that in an isolated system entropy inevitably increases.

figure 8 Typical trend in the magnitude of material flows through the economy in the various phases of the economic process



In principle, then, one might say that the initial input of materials to an economy is in fact synonymous with the waste arising during later phases. In a closed, autarchic economy this should actually take the shape of a law. In the real world, however, there are no such economies and in certain countries import and export flows may even account for over half the Gross Domestic Product. In establishing figures for the materials flowing through an economy this is quite a problem - for in which phase of processing are calculations to take place?

The most obvious answer, intuitively, is probably that it is the consumption phase that should determine the size of a country's material flows. After all, raw materials are not extracted just for the fun of it, but because there is a demand for them. That demand arises in the consumer market, for that is where the demand for particular functions arises that ultimately results in demand for materials embodied in certain products, in turn creating demand for refined and raw materials[13]. The most logical steering mechanism is therefore to bring pressure to bear on consumption choices at the household level. In practice, however, this leads to an untenable situation, for we have no real idea about the material composition of most of the tens of thousands of articles we consume each year, let alone the magnitude of the waste fraction arising in the upstream links in the supply chain. To seek an indicator providing a precise indication of the environmental consequences of our material consumption is therefore akin to a quest for the Holy Grail: although a number of people have reported seeing it, it is a figment of the imagination.

[13] Obviously, this is not simply an autonomous process: if there are economic externalities, for example, governments can steer this information flow. Thus, policy relating to greenhouse gas emissions will ultimately reflect back to some extent on demand for certain materials as energy-guzzling industries finds themselves faced with an energy tax.

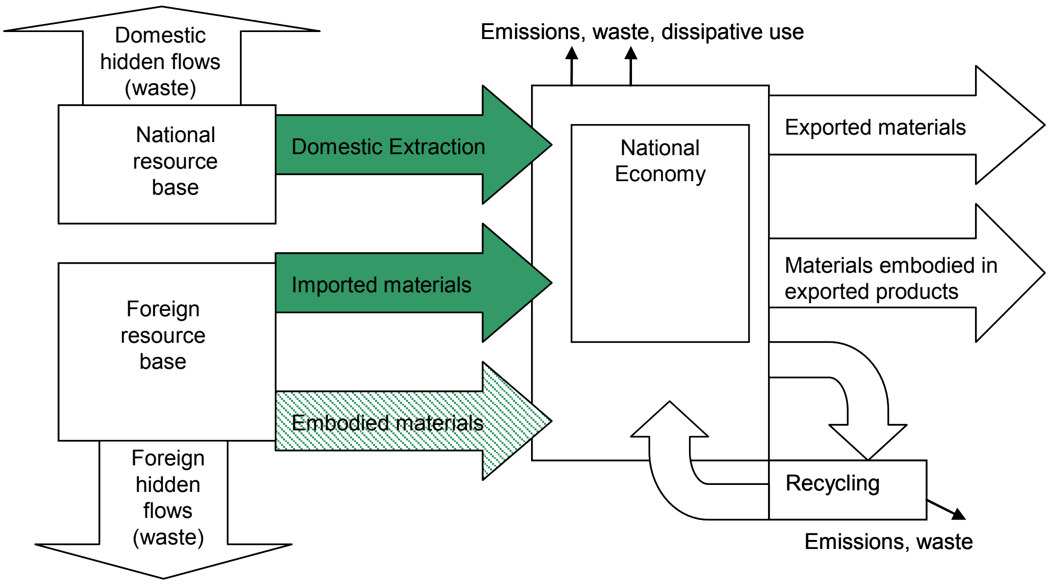
2.3.3 System boundaries: existing indicators for economy-wide MFAs

In the scientific literature a range of indicators have been developed that seek to measure all the materials flowing through the economy in kilograms [Andriaanse *et al*., 1997; Matthews *et al*., 2002]. It is these indicators that are generally seen as the tools at hand for monitoring an economy-wide material flow policy. In this section we provide a brief review, looking at how they are constructed and how they relate to the policy objective set out in general terms above.

Direct Material Input

The indicator most commonly used today is Direct Material Input (DMI), a measure of the kilograms of materials flowing into an economy. Figure 9 provides a conceptual scheme.

figure 9 Indicators: DMI[14]



As can be seen from figure 9, DMI is calculated by adding up all the material inputs to an economy, whether these derive from domestic extraction (mining and agricultural crops) or from imports (of both raw materials and materials embodied in products). Kilogram figures for the category 'embodied materials' are not always available and these must then be estimated from trade statistics[15].

DMI provides a measure of the material inputs to an economy in kilogram terms. The underlying notion is that sooner or later all these material inputs will leave the economy as emissions and waste. As argued in the previous section, this may be the case at the global level, but it does not necessarily hold true for specific individual countries. In practice, many materials leave the (national) eco-

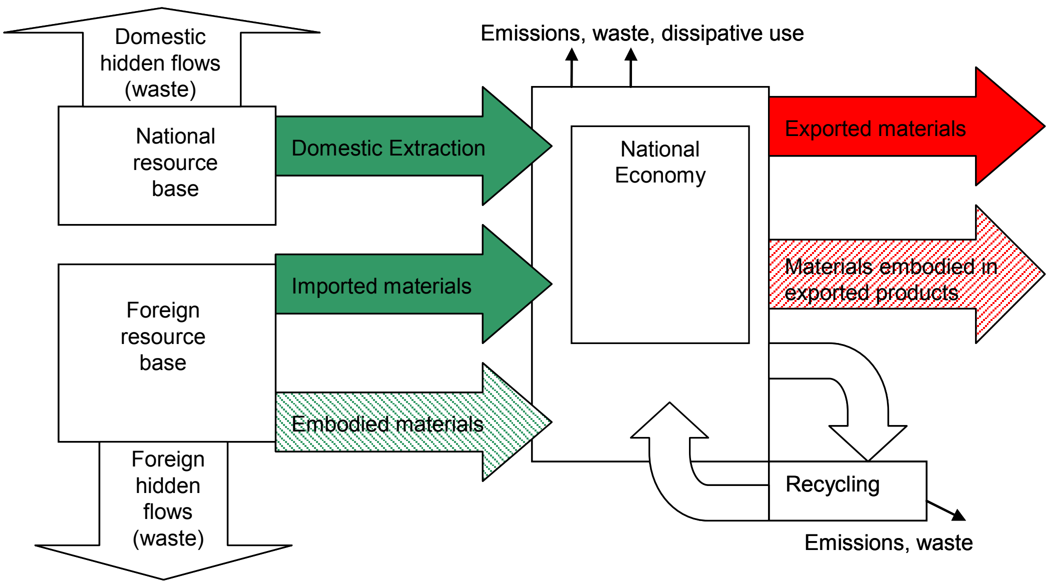
[14] *Legend to figures 9, 10, 19 and 20.* Data contributing to the indicator in a positive sense are shown in green, those to be deducted from the green data to yield the indicator in red. Hatched areas represent data that must sometimes be estimated for lack of empirical data on the flow in question.

[15] In a number of EU countries, kilogram trade statistics are available.

nomy as exports and changes in DMI over time therefore often prove to reflect mere changes in export patterns. Countries with a large export sector have a higher DMI than non-exporters and the implicit policy objective behind DMI is therefore to reduce trade flows - which cannot possibly be the purpose of an environmental policy indicator. For this reason, DMI would seem to simply disqualify itself as an indicator for any 'economy-wide material flow policy'. Whether we are interested in national trends or inter-country comparisons, there will always be other factors involved that have nothing to do with the aim of an economy-wide material flow policy, which is our concern here[16].

An alternative indicator, and the one recommended by Eurostat, is Direct Material Consumption (DMC), shown schematically in figure 10.

figure 10 Indicators: DMC



Note: for explanation, see legend to figure 9.

As can be seen, DMC is equivalent to DMI minus exports (materials and products). What the DMC in fact represents is the amount of materials remaining behind in an economy, which can be taken as equivalent to additions to existing material stocks (dwellings or consumer durables, for example) and dissipative effects such as emissions and waste.

Does this make DMC a useful indicator for an economy-wide material flow policy? This depends ultimately, above all, on the relationship between kilogram weight and environmental impact. DMC aggregates material flows on the basis of weight and is unable to distinguish flows of individual materials, as the category of embodied materials must be estimated from trade statistics. It is a gargantuan

[16] The Total Material Requirement (TMR) developed by the Wuppertal Institute suffers from the same problem as DMI. TMR differs from DMI in including the indirect (hidden) flows associated with the imported materials (the 'rucksack' remaining in the country of origin). This indicator is therefore not suitable for monitoring an economy-wide material flow policy, either.

task to use trade statistics to estimate the kilos embodied in imports of radios, say, let alone kilos of materials A, B and C - and most likely through to Z and beyond. For this reason, DMC has no alternative but to use weight as a basis for aggregating flows.

A second issue relates to 'hidden flows', which often take the shape of mining wastes accumulating in the country of extraction. That these hidden flows are not captured by DMC leads to a greater or lesser amount of distortion, depending on the structure of the economy in question. Thus, a country importing all its raw materials will have a far lower DMC than a country relying largely on its own domestic resources[17]. Some people argue that hidden flows (wastes arising during extraction of materials from nature) should most definitely be included in the overall analysis: after all, their contribution to the environmental burden is often significant, while being ignored by DMC[18].

Finally, there are a number of idiosyncrasies in the DMC system definition. Exports of materials, in whatever phase, decrease the value of the indicator. Consequently, a country exporting its wastes will have a lower DMC than a country processing its wastes domestically. However, this kind of idiosyncrasy could be remedied by minor adjustments to the overall system.

2.3.4 Aggregation: is weight a measure of a material's environmental impact?

DMC stands for the total amount of materials flowing into an economy, whether through domestic extraction or as imports, minus the total amount leaving the economy as exports. This indicator aggregates all material flows on the basis of weight. A key question, then, is the extent to which weight can serve as a yardstick for the environmental impact associated with a particular material.

Using the data compiled for the present study on Dutch consumption of 35 materials and their environmental impact (see Chapter 3 *et seq.*), we can plot the empirical relationship between weight and environmental impact on a graph, see figure 11[19].

As can be seen in the figure, sand and animal fats occupy the two most extreme positions of the spectrum: sand is extremely bulky, with extraction relatively benign, while animal fats are associated with substantial environmental impact

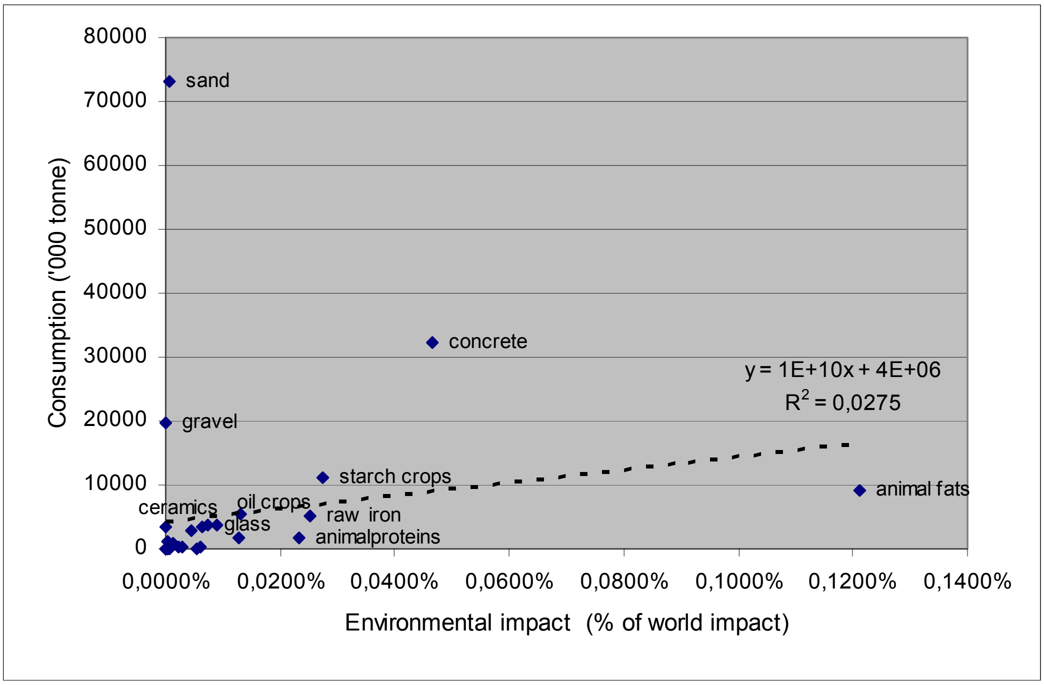
17 It might be remarked that this last objection need not in fact be a drawback, as economic structure also influences CO_2 emissions, for example. In climate policy, however, the policy objective has been defined such that changes in economic structure *do* have a part to play in reducing CO_2 emissions, because these emissions accounts are drawn up on a territorial basis. In the case of economy-wide material flow policy, on the other hand, the policy goal is to reduce the overall environmental impact of materials consumption, regardless of where that impact arises. Changes in production structure should not therefore have any impact on the indicator, because it would then no longer provide an accurate yardstick.

18 TMC (Total Material Consumption) is an indicator that does incorporate (estimated) hidden flows, expressed in kilograms.

19 In figure 11 the y-axis shows Dutch consumption of the material in the year 2000 and the x-axis the associated environmental impact, calculated as consumption times impact factor of the material (per kilogram) according to the method described in Chapter 3.

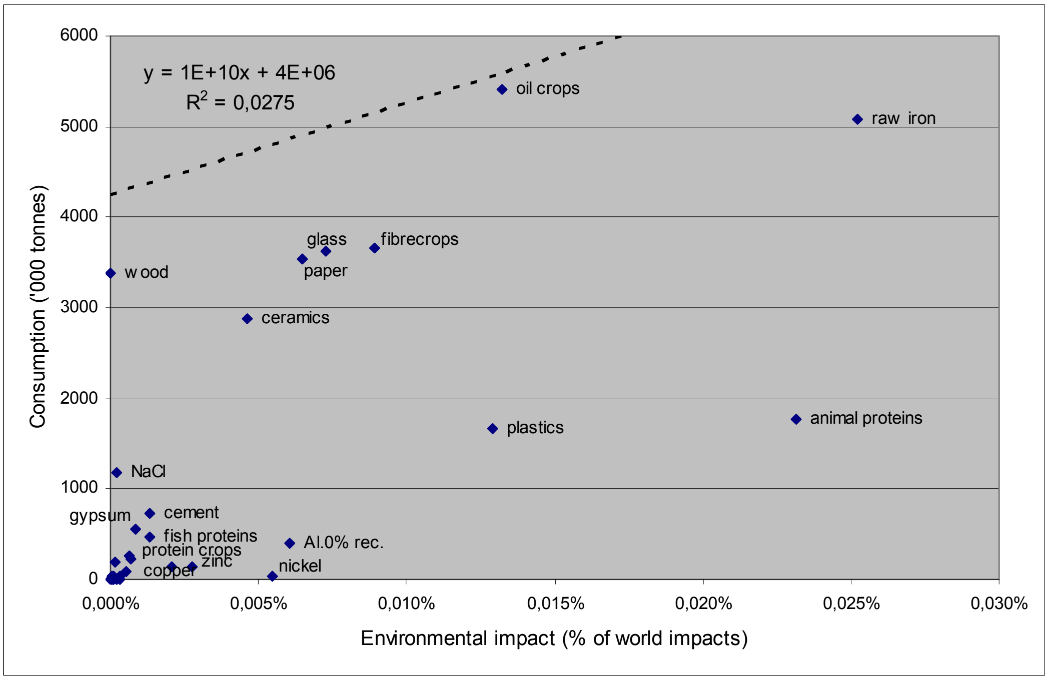
but relatively light-weight. Simple regression analysis shows that there is no relationship between the weight of materials and their environmental impact.

figure 11 Relationship between consumption (in kg) and cradle-to-grave environmental impact for 34 materials; Dutch data for the year 2000



Zooming in to the bottom left corner of the graph where most materials are plotted, there is still absolutely no relationship between weight and environmental impact (figure 12).

figure 12	Relationship between consumption (in kg) and cradle-to-grave environmental impact for 29 materials; Dutch data for the year 2000



As these graphs clearly show, weight is in no way a measure of the environmental burden associated with individual materials.

This leads to several conclusions regarding use of DMC as an indicator for an economy-wide material flow policy:

- DMC is probably not a good measure of the environmental impact associated with the use of natural resources[20].
- There may of course be a correlation between trends in DMC and environmental impact if the relative composition of the material flows remains unaltered while the total material flow decreases, as a result of dematerialisation, for example. In the short term, within a particular country, DMC may therefore serve as an *early warning system*. As each country has its own particular material flow signature, however, it cannot be used for inter-country comparison.
- The effects of materials substitution cannot be assessed using DMC. In point of fact, DMC does not even permit such substitution as a possible strategy in an economy-wide material flow policy.

[20] One should bear in mind, however, that there does not exist something like a DMC for single materials.

2.3.5 Towards an environmentally weighted indicator for material flows

As the above analysis makes clear, existing indicators for economy-wide material flow policy do not accord with the policy objective one would like to see for such policy. There is therefore a need to modify these indicators. One adjustment with which we have experimented in the present study is to weight the indicator using LCA results, a move proposed earlier by [De Bruyn *et al*., 2003] and [Van der Voet *et al*., 2003]. Here, we provide a brief description of the steps required to construct such an indicator, with further elaboration following in the next chapter.

The modified indicator, to be termed EMC (Environmentally weighted Material Consumption), is defined as:

EMC = Materials consumption * Environmental impact

or, mathematically:

$$EMC = \sum_{k} \sum_{i} M_i * E_{i,k}$$

where M_i is the material consumption of material i, E_i the cradle-to-grave environmental impact of that material and k the number of environmental impacts (global warming, acidification, etc.) included in the analysis. The environmental impacts can be taken from any operational LCA database. In this study we used the 1996 ETH database, which was the most up-to-date complete LCA database when we began the project. (An update is meanwhile available.)

Before this indicator can be elaborated, choices must be made on a number of points:
1 At what point in the supply chain is materials consumption to be measured (definition of M).
2 What materials are to be included in the analysis (choice of index i)?
3 What environmental impacts are to be included in the analysis (choice of index k)?
4 How are these environmental impacts to be aggregated?

In the next chapter we shall justify the choices made on each of these counts.

3 Constructing an environmentally weighted indicator

3.1 Introduction

As chapter 2 made clear, environmental impacts must be duly weighted if an indicator for an economy-wide material flow policy is to have any relation with the intended aim of such a policy, *viz.* to reduce the environmental burden associated with materials consumption.

More specifically, it became clear that several choices must be made regarding system boundaries that, in contrast to the indicators DMI and DMC, are not immediately self-evident.

In designing an indicator for material flow policy, there are four basic decisions to be taken:
1 Where in the supply chain are the material flows to be measured?
2 How is the environmental impact of these material flows to be calculated?
3 What materials are to be included in the analysis?
4 How are the environmental impacts to be aggregated?

In this chapter the methodological choices made in developing what we feel to be an effective indicator are explained. Specific problems relating to the definition of a 'material' are discussed in Appendix D, as are the calculations performed on the data to arrive at quantitative indicator values and the sources used to quantify consumption flows.

3.2 Where in the supply chain are material flows to be measured?

Before the environmental impact of a material can be calculated, it is essential that a clear choice be made regarding the *locus* in the supply chain we are referring to when we use the term 'material'. Although we shall always be assessing environmental impact all the way down the supply chain, from cradle to grave, there is still a need to define the notion of 'material consumption' with reference to one specific link in the chain, for otherwise there will be double-counting. The problem is illustrated in figure 13.

figure 13 Supply chains: from raw material to finished material

		many intermediate levels possible				
raw materials		**materials**	**materials**	**finished materials**	**products**	**functions**
water	water	water	water	water	water	subsistence
ores	iron ore	iron	pig iron	steel	cars	construction
	bauxite	aluminium	aluminium	aluminium	cans	packaging
	zinc ore	primary zinc	zinc	zinc (construction)	gutters	house protection
		secondary zinc	zinc oxide	zinc oxide (additive, pigment)	fodder	agricultural sector
	copper ore	primary copper	copper	copper (construction, wiring)	etc	
		secondary copp	copper oxide	copper oxide (additive, pigment)		
	lead ore	lead	lead	lead		
	chromium or	chromium	chromium	chromium		
	nickel ore	nickel	nickel	nickel		
	rare earths	palladium	palladium	palladium		
		platinum	platinum	platinum		
		rhodium	rhodium	rhodium		
	etc.	etc.	etc.	etc.		
minerals	silica sand	glass	glass	glass	bottles	packaging
					window glass	construction
	construction	construction sa	construction san	leveling sand	height	construction
			concrete	concrete	prefab elements	construction
	gravel					
	clay		ceramic	ceramic	tiles, bricks	constructiom
	limestone					
	asbestos					
	rock etc.					
	salt	chlorine				
		NaOH				
	N_2 gas	NH_3	N-fertiliser	crops	bread	food
	P-rock	P-acid	P-fertiliser	animal biomass		
	potash	potassium	K-fertiliser			
	sulphur					
	bentonite					
	gypsum					
	etc.					
biomass	wood		woodchips	paper	notebooks	packaging
			roundwood	board	window frames	construction
fossil fuels	oil	energy (heavy oil)				energy
		energy (light oil)				
		energy (diesel)				
		energy (petrol)				
		ethylene	PE	PE	pipes	construction
		propylene	PP	PP	window frames	construction
		styrene	PS	PS	bags	packaging
		vinyl acetate	PVC	PVC		
		benzene	etc.	etc.		
		phenol				
		active elements	pesticides			
		etc.				
	gas					
	coal					
	production	use				
	production		use			
	production				use	
	production					use

As the figure shows, there is a gradual progression from raw materials to product. The first column lists some illustrative raw materials (i.e. natural resources) under several key headings, in the second column specific materials are mentioned. The third column lists some of the materials derived from these resources, a few of which are used without undergoing any further processing. This process may be iterated a number of times before we arrive at the product level, in the sixth column. The key problem, now, is that some materials are used partly as a feedstock for other materials, while themselves also serving as a finished material.

It is consequently extremely difficult to opt for a *locus* midway along the supply chain or product life cycle. If we are to make a coherent choice as to where 'material consumption' is to be measured, there are in fact only two options: right at the start, at the raw materials level, or further down the chain, at the level of finished materials[21].

3.2.1 Raw materials level

Defining 'materials' at the level of raw materials (first column in figure 13) yields the best match with existing MFA databases and indicators derived from them. The advantage of this approach is that data on production, import and export of these materials are already available from other sources (see [Eurostat, 2002]). A second key point is that completeness is in theory guaranteed, as all the main flows of materials in the contemporary economy are covered. One drawback of this approach, however, is that it is extremely coarse. Because the main focus of the MFA database is on heavy, bulk flows, there is a danger of certain low-volume yet possibly very polluting material flows being forgotten. A second drawback is that defining 'materials' at the level of raw materials makes it very difficult to assess environmental impacts. Raw materials are used to produce a multitude of processed materials, which are in turn used in any number of applications. Because there are only a fairly limited number of raw materials, the supply chain emanating from each will be enormously diverse. The indicator score for 'sand', for example, will then comprise not only consumption of sand as a finished (unprocessed) material, but also that of glass, cement and concrete. Each of these materials has its own specific environmental profile. If there is to be meaningful assessment of environmental impacts, then, in this approach there must be complementary information on finished materials. A third drawback is that materials consumption calculated at this level mainly reflects the size of a country's basic industries. There is thus a risk of the indicator providing information on one particular aspect of economic structure rather than anything else.

3.2.2 Finished materials level

The second option for creating a coherent and consistent system is to define 'materials' at the level of finished materials, i.e. one step removed from being embodied in an end product. Thus, in the case of agricultural products we would take dry grain or cotton fibre, for example, rather than bread or textiles. In the case of glass, raw glass is the material rather than bottles or window panes, or sand, although these materials are all part of the glass supply chain. This approach, too, allows us to avoid double-counting. It is also more in line with what one would imagine a material flow policy to actually encompass. An added advantage is that data at this level are available from production and trade

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21 Although an intermediate *locus* is theoretically feasible, it then becomes almost impossible to avoid double-counting. There may nonetheless be other, non-substantive reasons for adopting a 'hybrid', intermediate level comprising materials midway down the chain as well as materials at the head or tail end. The main advantage of such an approach would be that a specific level of interest can be chosen for each material, increasing the usefulness of the ensuing list of materials. The main drawback, however, is the lack of robust systematics, making it difficult if not impossible to construct an aggregated indicator.

statistics, although these are not entirely comprehensive. The main drawback of this approach is that some materials remain invisible, as it were, because they serve solely as a feedstock for other materials. Artificial fertilisers contribute to the score of agricultural materials, for example, but do not count as materials in their own right, as they are used solely for agricultural production. There is also a danger of the list of materials becoming so lengthy as to make indicator calculation extremely time-consuming. Finally, consumption of finished materials is above all a reflection of the size of a country's manufacturing industry, for it is here that finished materials are consumed in the manufacture of end products.

3.2.3 Proposal for an indicator design

Our proposal is to adopt the level of finished materials as the *locus* for measuring material flows. Given current data availability, we feel this allows us to combine fairly robust systematics with a choice of policy-relevant materials, some of which might otherwise remain hidden from view.

Policy relevance indeed served as a key motive for opting to base the indicator on finished materials. In fact, the policy potential of a material flow policy is governed to no small part precisely by the *locus* adopted. As an illustration, table 1 shows some of the measures that might be applied at various stages in the supply chain for metals.

table 1 Examples of material flow policy options at various stages of the (metals) supply chain

	Processing stage (input material)		
Policy effects	Mining (minerals/ores)	Refining (raw materials)	Manufacturing (finished materials)
Substitution	n.a.	more concentrated ores (more benign profile substitution)	Product design: Material substitution, use of recycled materials, use of more benign materials (profile substitution)
Recycling / reuse	Reuse of mining tailings	Reuse of scrap	Reduction of rejects, reuse, recycling of input materials
Dematerialisation	n.a.	Strengthening of material properties	Make lighter products or increase product lifetime

As can be seen, there are no options for substitution or dematerialisation at the mining stage and only limited scope for such action at the refining stage (in this case the basic metals industry). For all three policy handles there is greatest potential at the manufacturing stage of the life cycle. This is not surprising, as it is here that decisions are made as to how products are to be manufactured and what materials are to be used to that end. For these reasons, defining material consumption at the level of finished materials is preferable to doing so at the raw materials level.

Consumption of finished materials can then be expressed as the result of the following addition and subtraction:

production plus *imports* minus *exports of the material.*

This is the same as ‘apparent consumption’, which has been frequently used to measure national-level materials consumption (see for example [Malenbaum, 1978]; [Williams *et al*., 1986]; [Tilton, 1990]). The predicate ‘apparent’ relates to the fact that we have no knowledge of whether the material in question has actually been consumed or simply added to existing stocks.

3.3 Calculating the environmental impact of an individual material

3.3.1 Material-related environmental impact

To calculate the environmental impact associated with an individual material we adopt the approach elaborated in [Van der Voet *et al*., 2003], which can be summarised as follows:

- Materials are followed through their entire life cycle, from the ‘cradle’ of raw material extraction or harvesting to the ‘grave’ of final waste disposal.
- The analysis includes not only the material itself but also the energy and auxiliary materials required for production, use and waste disposal.
- The entire array of environmental interventions occurring down the supply chain (emissions, extractions, land use, etc.) is specified in quantitative terms.
- These are then weighted and summed to yield a limited number of ‘impact categories’, or environmental problems, that together yield an overall measure of environmental impact.
- The analysis does not include the energy used by end products like a coffee-maker, as that energy is not directly related to the material itself (although it may be influenced by it). This aspect falls under ‘product policy’ rather than ‘material flow policy’.

For calculating overall environmental impact we made use of the ETH database [Frischknecht, 1996] and the CMLCA program [Heijungs, 2003]. The database provided the data on material supply chains and environmental interventions, while CMCLA converts these to contributions to impact categories and facilitates processing of the results in various formats. Using a standard database and software has the advantage that these have gained a measure of universal acceptance in the LCA world (scientists as well as users). It may safely be assumed that errors will be discovered and new developments included in future versions. There is also criticism on a number of counts, which we shall now discuss.

With respect to the ETH database, the first thing to be noted is that it is not specifically geared to the Netherlands, but based on ‘average’ West European processes. This may mean the results are not characteristic of the Dutch situation. This is particularly true of electrical power generation and certain industrial processes, but may also well apply to some forms of waste processing and disposal. If these data are used to support a Dutch material flow policy, this approach will therefore yield no more than a rough-and-ready indication of a material’s environmental impact, with additional calculations being necessary on specific details. At the same time it should be noted that the non-specificity for the Netherlands need not always be a disadvantage. A large number of materials are imported and thus produced elsewhere. For many materials, imports and exports in fact by far exceed production. One category of materials that are usually produced domestically, however, are construction materials and for these it is particularly important to check the database results against the local Dutch situation.

The second point about the ETH database is that it dates back to 1996 and is thus somewhat outdated. A new version of the database known as EcoInvent was recently launched. Unfortunately, though, it came too late for it to be used in the present study.

We determined environmental impacts with reference to three distinct phases of the life cycle:
- Extraction and production.
- Use.
- Final waste.

Data on the extraction and production phase were taken from the ETH database. This was not the case for the use phase, for which we made our own estimates. It is important to note here again that the environmental impact in the use phase does not include the energy consumption of appliances (co-)manufactured from the material, for reasons already noted. What we did do, however, was estimate emissions from the material itself. With respect to the final waste phase, in some cases the database contained sufficient data, but in others we had to make some assumptions of our own. The issue of waste is not dealt with consistently in the ETH database. It was not within the scope of the present study to improve the ETH data as such, however. A more detailed description of the choices made with respect to each of the three phases is provided in Appendix J.

The next step was to add up the scores for each of the three phases of the life cycle to create an array of cradle-to-grave contributions to each individual LCA impact category. This then provides a basis for comparing materials.

In this project we adopted the following set of LCA impact categories:
- Abiotic resource depletion.
- Land competition.
- Global warming.
- Ozone layer depletion.
- Human toxicity.
- Ecotoxicity: Aquatic, Marine and Terrestrial.
- Photochemical oxidant formation.
- Acidification.
- Eutrophication.
- Ionising radiation.
- Final solid waste.

These are the categories specified in the 'Handbook of Life Cycle Assessment' [Guinée *et al*., 2002] that are sufficiently developed to apply. Together, these provide fairly comprehensive coverage of the known spectrum of environmental problems. They are also equivalent to what are referred to in the OECD framework as environmental pressure variables [OECD, 1993]. An alternative would be to define impacts at the level of 'end points', as 'stress variables' in OECD parlance, i.e. damage to human health, loss of biodiversity, landscape degradation and so on. The idea of the aforementioned 'mid-point' LCA categories, however, is that they all contribute to end-point impacts, which need not therefore be included again as such.

3.3.2 Interpretation and aggregation

By multiplying the volume data on apparent consumption of the principal materials by the environmental impact per kilogram of each, we can gain an impression of their relative contribution to overall environmental impact. This allows us to compare materials and establish which are to be given priority in a material flow policy.

This comparison was carried out first for each individual impact category. Thus, we drew up separate 'top twenties' for global warming, land competition and so on. Obviously, these lists will not be the same each time, nor are they likely to consistently contain the same materials. This may well provide useful information for policy on individual environmental 'themes'. For the purpose of a general material flow policy, however, we need to add a final step, aggregating the scores for the various themes to a single figure for 'aggregate environmental impact' in which the individual impacts are appropriately weighted.

Aggregation to a single-figure environmental score has, for years, been a contentious issue in LCA circles and beyond, for any such aggregation will always have a subjective element. In the spectrum of opinions on this matter some hold that there should consequently be no weighting at all, with policy-making based on qualitative evaluation of the whole array of Life Cycle Impact Analysis results. Others argue that in a policy-making context there will always be some kind of weighting, explicit or implicit, and it is therefore preferable to adopt a formal procedure for that purpose, as that will at least render the criteria transparent.

Opinions also differ on the weighting procedure to be adopted, ranging from expert opinion via subjective (political) weighting through to monetary weighting. In the present project we make no pretence of settling this debate. Nonetheless, if we are to construct a single, aggregated indicator for measuring the environmental impact of materials consumption, there is no escaping some form of weighting. We therefore propose to experiment with several options. This serves a dual purpose, yielding insight into the importance of the weighting step as such as well as into the overall robustness of the indicator. It is important that the weighting method adopted be sufficiently complete in its coverage, though, something that unfortunately does not hold for all sets of weighting factors. For example, certain weighting methods focus above all on energy and energy-related environmental problems such as climate change and acidification.

The following sets of factors are used in practice, and claim to be more or less complete:

- The NOGEPA weighting factors, established by a panel of policy-makers, scientists and industry representatives, and occasionally used in a practical context.
- Ecoindicator 99, which seeks as far as possible to model processes through to end-points, to capture a maximum number of impacts under the same denominator.
- Shadow prices, an economic weighting method based on the cost of mitigating the environmental impact in question.
- EPS, a method using 'Willingness to Pay' to weight emissions, extractions and so on.

These methods will be augmented by a straightforward method in which all the LCA impact categories are equally weighted.

The various weighting methods are treated in greater detail in Appendix H.

3.4 Choice of most environmentally damaging materials

Ideally, one would wish to construct an indicator covering each and every material, simple or compound. In practice, however, one is confronted with serious data problems, as not all materials or material flows are monitored equally well, if at all. In the specific case of the Netherlands, for example, the national statistical office CBS presently has no standing programme for estimating materials consumption in physical units. This meant it was beyond the scope of the present study to estimate the volume consumption of each *finished material* and a choice therefore had to be made as to which materials to include in the pilot version of the EMC and which to omit.

There are several obvious criteria that can be used to decide which materials to monitor and include in an indicator for a material flow policy. Thus, the focus may be on any of the following:

- The most environmentally damaging materials.
- Materials for which substitution, recycling/reuse and dematerialisation can potentially provide substantial policy leverage.
- Materials for which no additional policy has yet been formulated.

In this study we have based ourselves mainly on the first of these criteria. After due consultation with the steering committee, we propose construction of an indicator covering the twenty most environmentally damaging materials in use in the Netherlands.

3.4.1 Materials included in this study

One of the criteria on which the choice of materials to be included in an indicator must be based is their contribution to overall environmental impact. The first step, then, is to estimate the environmental impact of as many individual materials as possible, which we did following the methodology described in [Van der Voet *et* *al.*, 2003]. To this end we used data from the aforementioned LCA database, supplemented with data from several dedicated LCA studies, to estimate the environmental impact per kilogram of each material. For as many as possible of these materials, annual consumption was then estimated, defined as Apparent Consumption (see section 3.2.3). For each material and for each impact category, these two figures were then multiplied and the results aggregated using several different weighting methods, as explained in section 3.3.2. The end result of this exercise is a set of material 'top twenties' according to alternative weighting methods.

The materials subjected to this first-pass analysis are listed in table 2.

table 2 Materials examined in the present study

List of materials for which a per kg impact is specified	**List of materials for which flow data are available**	**List of finished materials, excluding double counting**
Al2O3	Al2O3	aluminium
aluminium 0% Rec.	aluminium 0% Rec.	animal fats
aluminium 100% Rec.	aluminium 100% Rec.	animal fibres
ammonia	ammonia	animal proteins
animal products	animal fats	barite
AP	animal fibres	cement
barite	animal proteins	ceramic
bentonite	AP	chromium
blown steel	barite	concrete
board	CAN	copper
Ca(OH)2	CaO	fibre crops for clothing
CAN	cement	fibre crops for food
CaNO3	ceramic	fish proteins
CaO	chlorine	glass
cast iron	chromium	gravel
cement	concrete	gypsum
ceramic	copper	H2SO4
chemicals anorganic	copper additive to fodder	iron and steel
chemicals organic	fibre crops for clothing	lead
chlorine	fibre crops for food	NaCl
chromium	fish proteins	nickel
clay / loam	glass	oil crops
concrete	gravel	palladium
copper	gypsum	paper and board
copper additive to fodder	H2SO4	PC
crop or grass	HCl	PE
electrosteel	iron and steel	PET
ethylene	KNO3	platinum
ethylene oxide	lead	PP
explosives	NaCl	protein crops

List of materials for which a per kg impact is specified	List of materials for which flow data are available	List of finished materials, excluding double counting
FeSO4	naphta	PS
formaldehyde	nickel	PUR
glass (coated)	NPK	PVC
glass (not coated	oil crops	rhodium
gravel	palladium	rockwool
gypsum	paper and board	rubber
gypsum (raw stone)	PC	sand
H2SO4	PE	starch crops
H2SO4	pesticides	zinc
H3PO4	PET	
HCl	platina	
HF	PP	
HNO3	protein crops	
KNO3 (NK14-44)	PS	
lead hard	PUR	
lead soft	PVC	
limestone	rhodium	
manganese	rockwool	
MAP	rubber	
NaCl	sand	
NaOH	SSP	
nickel	starch crops for bioplastics	
nitro AP (52% P2O5, 8.4% N)	starch crops for food	
NPK 15-15-15 (mixed acid route)	sulphur	
NPK 15-15-15 (nitrophosphate route)	urea	
palladium	water	
paper	wood	
paraxylene	zinc	
PC	zinc additive to fodder	
PE (HD)		
PE (LD)		
pesticides		
PET 0% rec.		
phenol		
PK 22-22		
platinum		
PP		
PS		
PUR		
PVC		
raw iron		
refrigerant R134a		
refrigerant R22		

List of materials for which a per kg impact is specified	List of materials for which flow data are available	List of finished materials, excluding double counting
rhodium		
rockwool		
rubber		
sand		
SDAP		
soda		
SSP		
steel (high alloyed)		
steel (light alloyed)		
steel (not alloyed)		
styrene		
sulphur		
TSP		
UAN		
urea		
uream		
vinylchloride		
water (decarbonated)		
water (demineralised)		
wood (board)		
wood (massive)		
zeolith		
zinc		
zinc additive to fodder		

The first column of this table shows those materials for which per-kilogram impacts could be established using the LCA database. Although fairly extensive, the list is certainly not complete. Although bulk materials are well represented, data on materials used in smaller quantities (certain heavy or noble metals, for example) are frequently lacking. This may be a problem if such materials are so environmentally damaging, kilo for kilo, as to qualify them for a place in a top twenty despite their low volume consumption. At the moment, at any rate, this does not appear to be the case. This may change in the future, though, if materials like platinum, palladium or indium are used for mass production of fuel cells, say, or solar panels, computers or cellphones. Another category of materials that is likely to show substantial volume growth in the coming years are materials produced by the biotechnology industry, some of which are made from agricultural feedstocks. As yet, there is scarcely any commercial production or (probably) use of such crops in the Netherlands. The LCA database has no impact factors for these materials, nor have any as yet been appended. Appendix E looks at the issue of biomaterials in more detail. A full review of per-kg impacts for each of the impact categories distinguished in this study is to be found in Appendix I.

The middle column of table 2 lists the materials for which flow data could be found. This list is rather shorter, such data not being available for all the materials in column 1. Certain materials are reported as aggregate categories, moreover, so that the initial list of six varieties of iron and steel has now been reduced to a single category of iron/steel, for example. In other cases the middle column is more extensive, though, particularly in the case of biomass. Crops and animal products have been broken down according to the scheme shown in Appendix D. In the absence of more specific data, for all crops we took the same per-kg impact, so that differences in ranking are due exclusively to differences in volume consumption. The same holds for the entire range of animal products. Fish are also listed in the middle column. For fish we also derived supplementary impact factors, calculated as the average impact of farmed and wild fish, as explained in Appendix F.

The right-hand column, finally, lists the materials ultimately included in drawing up the thematic 'top twenties'. The main difference from the middle column is that it no longer contains any materials not in use as a 'finished material', in line with our choice of system boundaries (see section 3.2.3). Among the materials omitted are industrial chemicals, and fertilisers and pesticides used in crop production. The latter form part of the chain of agricultural products and to include them separately in the indicator would involve double-counting.

Proceeding from the list in this right-hand column, we multiplied the per-kg impacts by volume consumption to yield a top twenty of materials for each impact category. The results of this exercise are reported in Appendix G. Although there are clearly differences among the various impact categories, a number of materials recur. Despite agricultural products being broken down into several sub-categories, they still often rank high. Several bulk materials like iron and steel, concrete, cement and aluminium are also regular high-scorers. A number of heavy metals and plastics also recur in the various top twenties.

3.4.2 Top twenty most environmentally damaging materials according to various weighting methods

To obtain an overall picture we first 'normalised' the scores for the various impact categories, that is, divided them by *global* impact equivalents for each impact category[22], and then weighted the resultant figures before summing them. The index thus obtained represents the contribution of use of the material in question to aggregate global abiotic resource depletion, climate change, land competition and so on.

As explained above, to obtain a more refined picture of the materials contributing most to these problems, considered in their entirety, we experimented with five different weighting methods, *viz.* equal weighting of impacts, weighting with NOGEPA weighting factors, the Eco-Indicator 99 system, the shadow price method and the EPS method. These are all explained in Appendix H.

22 The relevant data can be found at http://www.leidenuniv.nl/cml/ss/index.html.

figure 14 Top twenty materials according to percentage contribution to environmental impact of Dutch materials consumption (equal weighting)

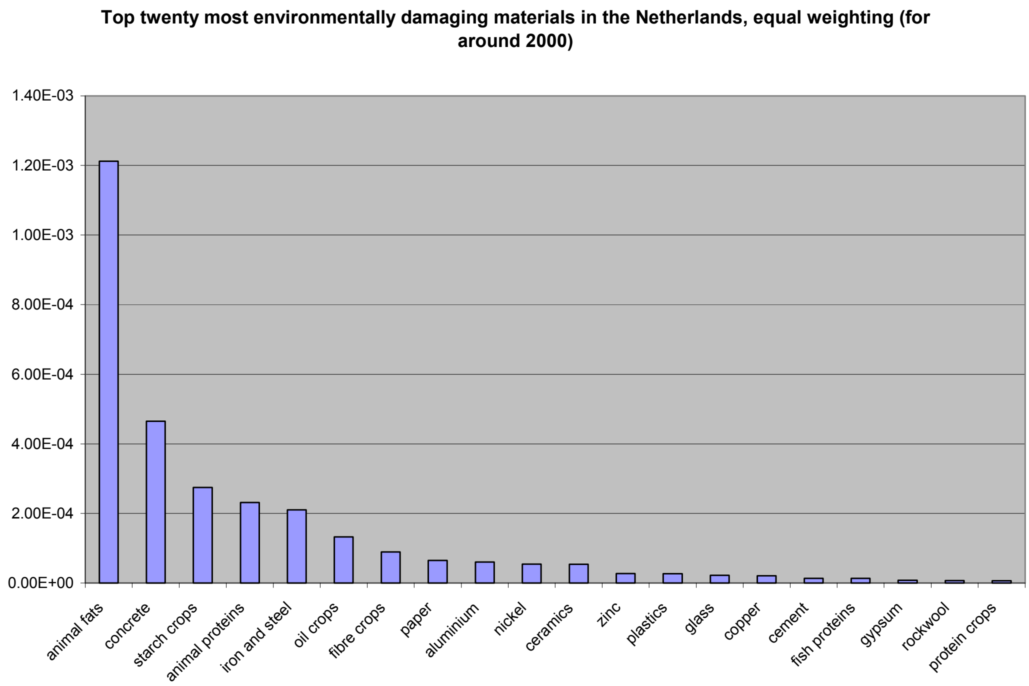
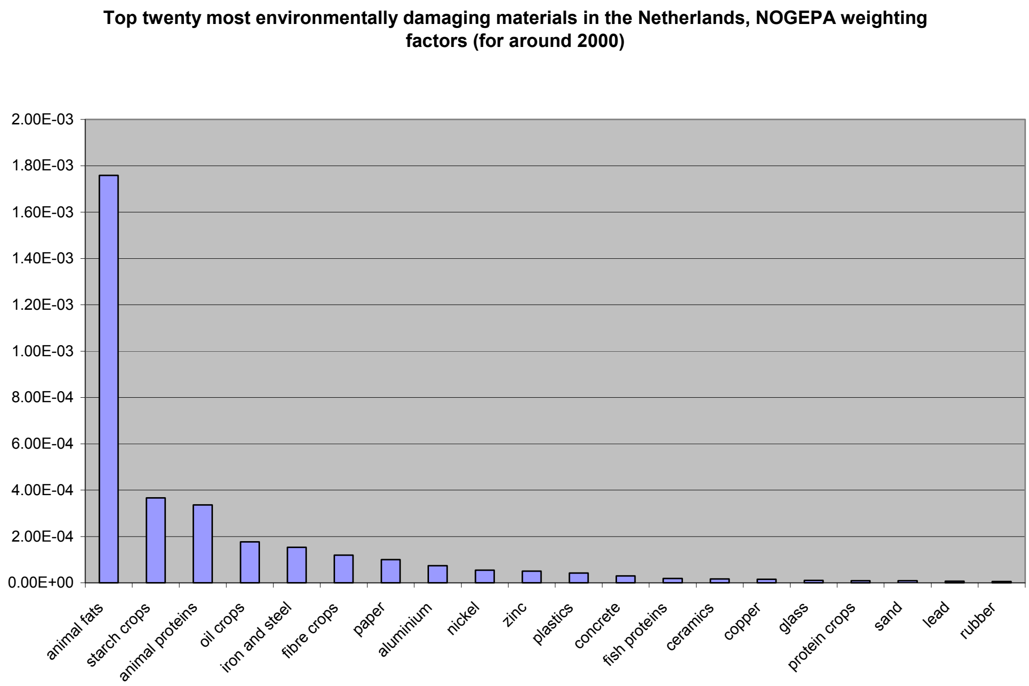


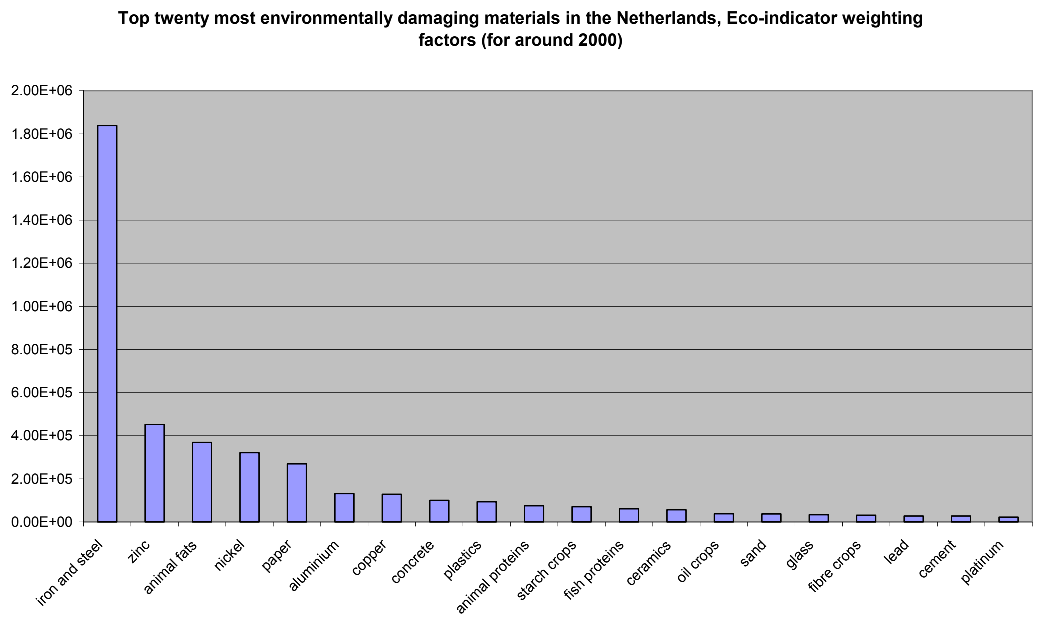
figure 15 Top twenty materials according to percentage contribution to environmental impact of Dutch materials consumption (NOGEPA weighting factors)



Figures 14 and 15 show the results of the first two weighting methods: equal weighting, in which each environmental theme contributes 1/13 of the total score, and weighting with the NOGEPA factors. In the 'equal-weight' top twenty, bulk materials like concrete and cement feature more prominently. This is probably due to the fact that final solid waste is not included in the NOGEPA scheme (an indication of the low priority assigned to this impact category). Iron and steel, aluminium, nickel, zinc and copper recur in both top twenties. The same holds for a number of materials of agricultural provenance.

The Eco-indicator is rather different in nature, employing a different set of impact categories and a different weighting method. The Eco-indicator focuses on three end-point impacts: damage to human health, damage to ecosystems and resource depletion, each with subcategories. Weighting then takes place across the subcategories (with equal weighting) and across all three categories. The results are shown in figure 16.

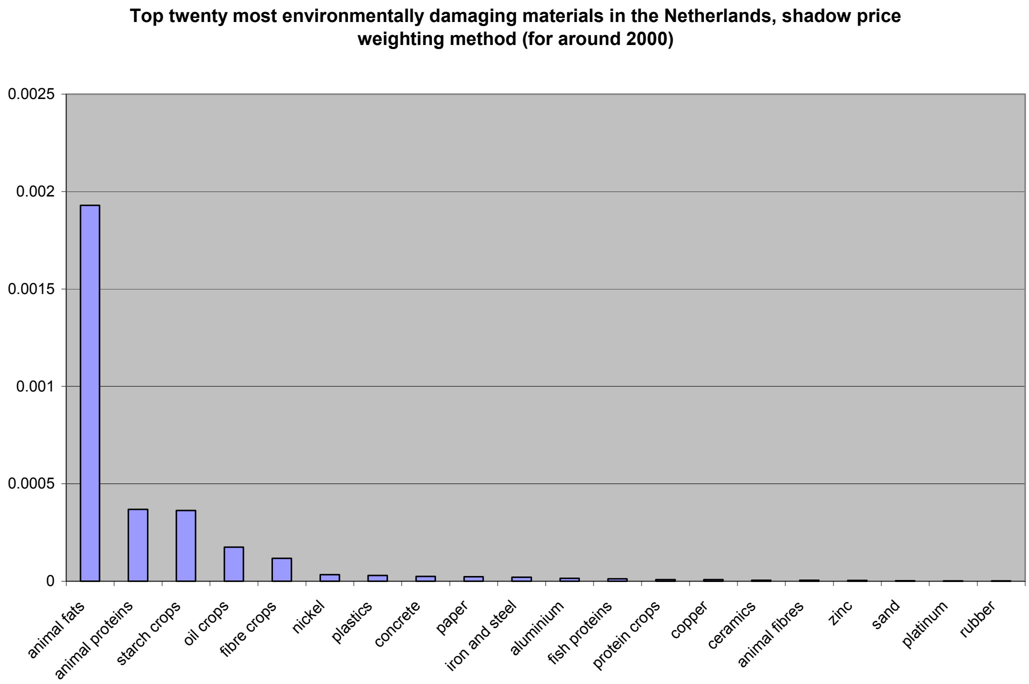
figure 16 Top twenty materials (Eco-indicator 99 weighting factors)



Although this ranking differs from both the previous ones, the materials in the top twenty are still largely the same. One general observation is that agricultural products now feature rather less prominently. This is due partly to the lack of any subdivision within this category of materials and partly to a greater weight being assigned to abiotic resource depletion, pushing metals and other energy-intensive resources higher up the list.

The fourth weighting method is the shadow price method [Davidson *et al*., 2002]. Here, the weights assigned to the various themes are derived from the costs of mitigating the impact of the respective environmental problems. The results are shown in figure 17.

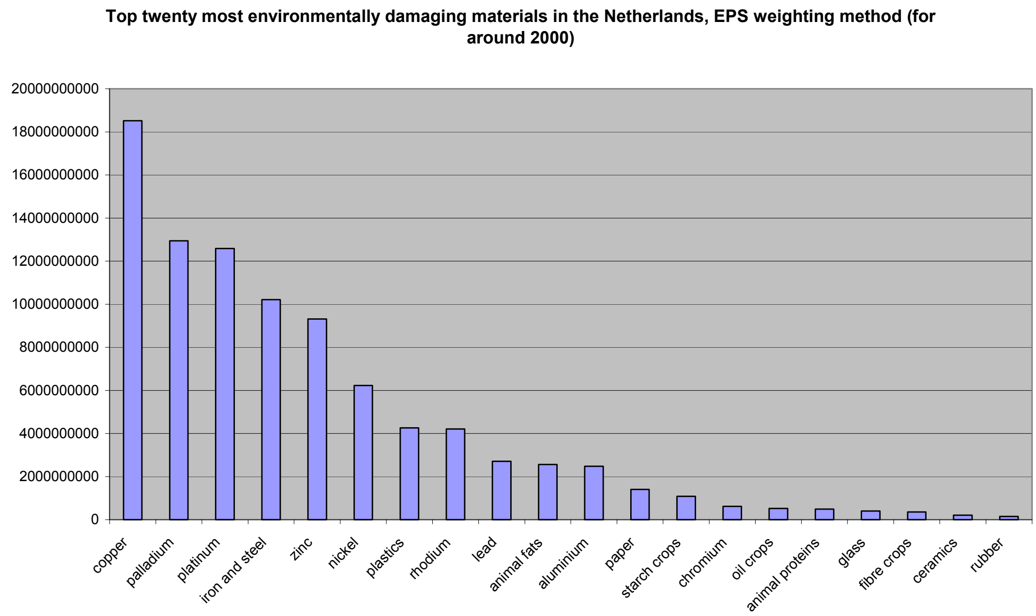
figure 17 Top twenty materials (shadow price weighting method)



This weighting method appears to put excessive weight on agriculture-related environmental themes, with even the relatively small flow of 'animal fibres' appearing in the top twenty.

A fifth weighting method in current use is the EPS method [Steen, 1996]. In this method extractions and emissions are weighted directly, using factors derived from estimates of Willingness to Pay. The results are shown in figure 18.

figure 18 Top twenty materials (EPS weighting method)



In this system, eight of the top ten materials are metals, including several noble metals from the final list of 'finished materials' that are used in extremely small quantities. The EPS weighting method implicitly attaches a great deal of weight to resource depletion, which thus overshadows all the other categories of environmental impact.

3.4.3 Choice of materials for inclusion in the indicator

Those materials that rank consistently high on these various scales must clearly be included in our indicator. At the same time, though, the weighting methods do yield differing results, sometimes strikingly so, as can be seen from the overview of table 3, in which the results are compared.

table 3 The 20 most environmentally damaging materials according to different weighting methods

Equal weighting	NOGEPA	Eco-indicator	Shadow prices	EPS
Animal fats	Animal fats	Iron and steel	Animal fats	Copper
Concrete	Starch crops	Zinc	Animal proteins	Palladium
Starch crops	Animal proteins	Animal fats	Starch crops	Platinum
Animal proteins	Oil crops	Nickel	Oil crops	Iron and steel
Iron and steel	Iron and steel	Paper and board	Fibre crops	Zinc
Oil crops	Fibre crops	Aluminium	Nickel	Nickel
Fibre crops	Paper and board	Copper	Naphtha	Plastics
Paper and board	Aluminium	Concrete	Concrete	Rhodium
Aluminium	Nickel	Plastics	Paper and board	Lead
Nickel	Zinc	Animal proteins	Iron and steel	Animal fats
Ceramics	Plastics	Starch crops	Aluminium	Aluminium
Zinc	Concrete	Fish proteins	Fish proteins	Paper and board
Plastics	Fish proteins	Ceramics	Protein crops	Starch crops
Glass	Ceramics	Oil crops	Copper	Chromium
Copper	Copper	Sand	Ceramics	Oil crops
Cement	Glass	Glass	Animal fibres	Animal proteins
Fish proteins	Protein crops	Fibre crops	Zinc	Glass
Gypsum	Sand	Lead	Sand	Fibre crops
Rockwool	Lead	Cement	Platinum	Ceramics
Protein crops	Rubber	Platinum	Rubber	Rubber

The first step now is to identify materials appearing in each ranking, as these are evidently crucial. Disregarding the results of the EPS method, with its overemphasis on resource depletion, the following 15 materials feature in the top twenties of all four other weighting methods:

Aluminium
Animal fats
Animal proteins
Ceramics
Concrete
Copper
Fibre crops
Fish
Iron and steel
Plastics
Nickel
Oil crops
Paper and board
Starch crops
Zinc

In addition, there are a number of materials featuring on two or three of the lists:

Glass
Protein crops
Sand
Cement
Lead
Platinum
Rubber

If we include this latter group in our indicator, we have a total of 22 materials. Of these, rubber cannot be distinguished as a separate flow in the Netherlands, there being no specific consumption statistics available. Because most of the rubber used in this country is synthetic, we have opted to include rubber with plastics.

As can be seen from the charts, agriculturally derived materials generally rank high. From an environmental policy perspective it would therefore make sense for these materials to be included in any indicator. An opposing argument, though, is that food (for this is what is generally involved) is already the specific subject of a dedicated policy field and should therefore be excluded from our indicator. After all, a similar line of reasoning was adopted above with respect to energy, which is why fossil fuels do not feature in the indicator. In order not to anticipate policy decisions in this area but still fruitfully pursue the present study, we opted to construct two indicators, one for food-related materials and one for materials *sensu stricto*, which in addition to traditional materials like iron, sand and plastics also comprises biomass flows not consumed as food (textile feedstocks, etc.).

Ultimately, we opted for the following two lists:

Food-related materials:
- Animal fats.
- Animal proteins.
- Fish proteins.
- Starch crops.
- Oil crops.
- Protein crops.
- Fibre crops for food.

Materials sensu stricto*:*
- Iron and steel.
- Aluminium.
- Copper.
- Zinc.
- Lead.
- Nickel.
- Sand.
- Concrete.

- Cement.
- Ceramics.
- Glass.
- Paper and board.
- Plastics (incl. rubber).
- Animal fibres.

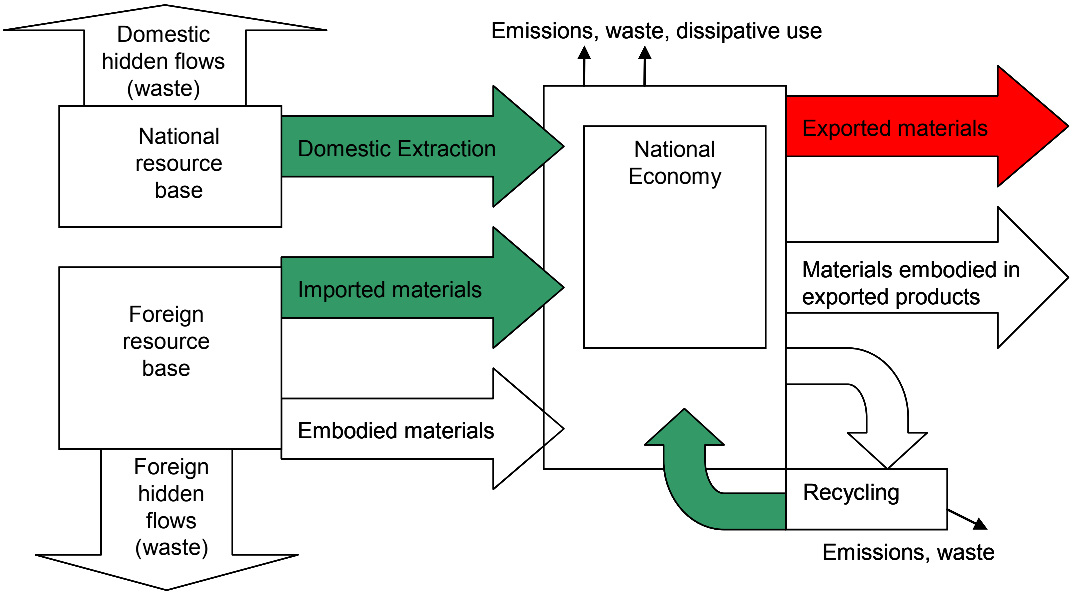
These, then, are the materials we have used in constructing the indicator in the following chapter.

3.5 Relationship with DMC and DMI

In the previous section a number of key choices were made for the elaboration of an environmentally weighted indicator for materials consumption, which we have termed EMC. How, then, does this indicator stand in relation to DMC and DMI?

Let us first recall that the volume data on which this EMC is based are rooted in the notion of 'apparent consumption', to be represented schematically as follows:

figure 19 Components of Apparent Consumption

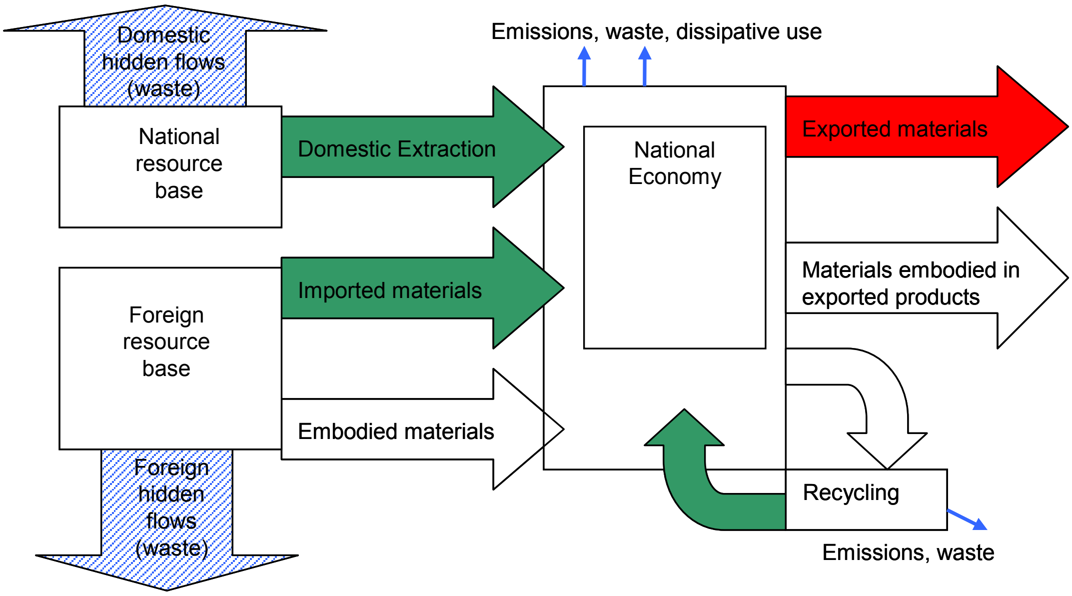


Note: for explanation, see legend to figure 9.

One advantage of this approach over both DMC and DMI is that the array of statistical data is in principle simpler and more transparent, because it is often possible to use standard statistics, with no need to estimate flows of embodied materials. The second advantage is that this approach recognises individual materials rather than aggregate flows (as with DMC and DMI), enabling these flows to be weighted according to environmental impact and the indicator to be used more effectively in a later phase of the policy cycle to address flows of specific interest.

Combining apparent consumption with data from LCA databases, the indicator EMC enables all the environmental impacts occurring from cradle to grave to be included under the umbrella of a material flow policy. This is illustrated in figure 20, in which the colour blue indicates the impacts that now come in for inclusion. In this approach, it is these impacts that ultimately determine the value of the indicator, rather than kilogram consumption of the material in question.

figure 20 Environmentally-weighted Apparent Consumption approach



Note: Blue indicates the impacts included in weighting of the material flows.

The principal advantage of this indicator in comparison with DMI and DMC is that it matches the intended and stated aim of an economy-wide material flow policy. It also has a drawback, however: accurate system boundaries are harder to set than in the case of either DMI and DMC, though decisions on this point will influence results[23]. In this study we have opted for apparent consumption at the level of finished materials, but it would be equally feasible to measure consumption at a different level of detail, yielding a different indicator. Another drawback is that to arrive at a uniform environmental indicator, information from the LCA database must be summed, requiring weighting of heterogeneous forms of environmental impact. Given the widespread debate on this issue, this may be a serious handicap for general acceptance of the EMC indicator in policy circles.

[23] For example, a greater effort must be made to avoid double-counting (see section 3.2).

4 Trends in EMC, 1990-2000

4.1 Introduction

To assess the variation in the EMC indicator over time we need statistical time series. The annual statistics we in fact need relate only to the apparent consumption of the materials in question, for in our method per-kilogram impacts of the materials remain unchanged, only coming up for review when a new update of the LCA database is released. This is entirely in line with the main purpose of this indicator: to assess the environmental consequences of changes in the composition and magnitude of the overall flow of materials through the economy. Appendix D details the principal sources from which these statistics were derived.

4.2 Trends in Apparent Consumption

Figures 21, 22 and 23, below, show trends in apparent kilogram consumption between 1990 and 2000: figure 21 for the full selection of materials, figure 22 for food-related materials and figure 23 for materials *sensu stricto*.

figure 21 Trends in kilogram consumption of 21 materials in the Netherlands, 1990-2000

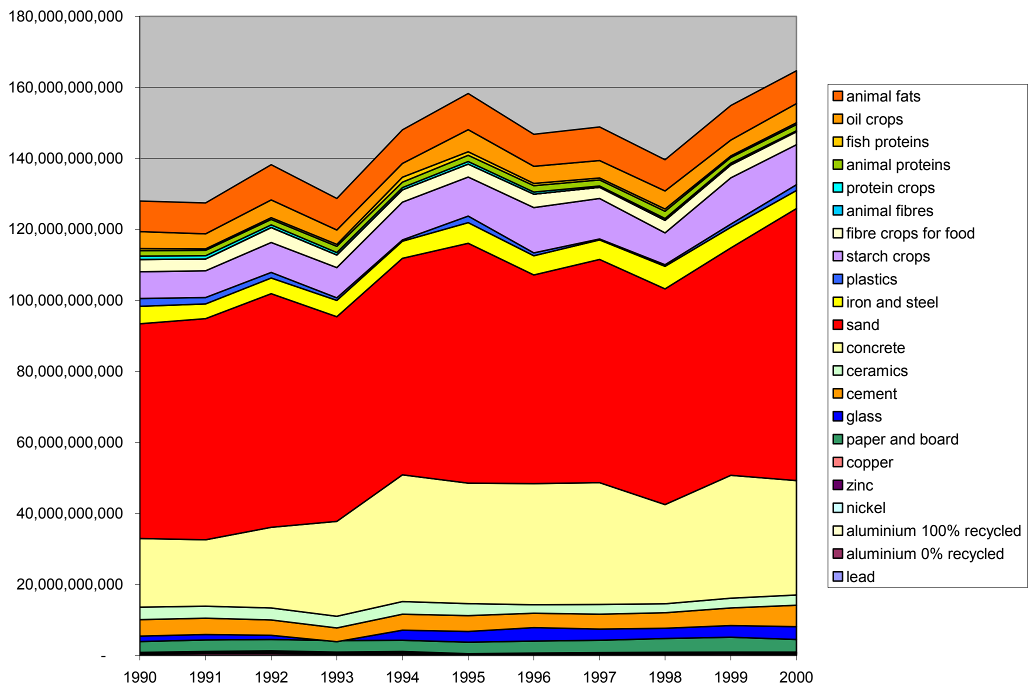


figure 22 Trends in kilogram consumption of 7 food-related materials in the Netherlands, 1990-2000

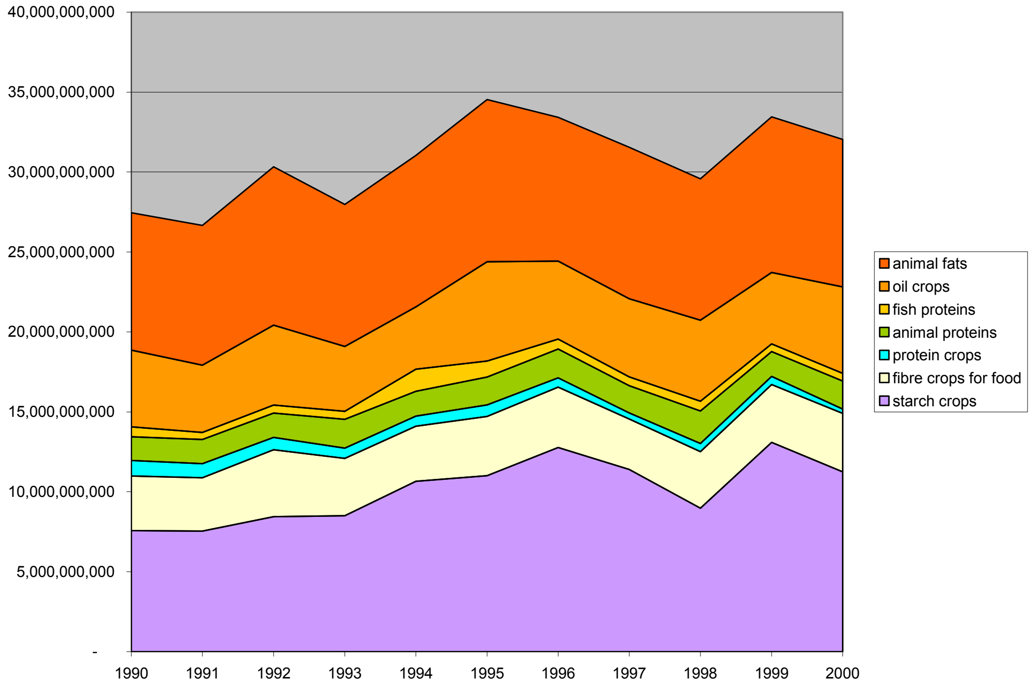
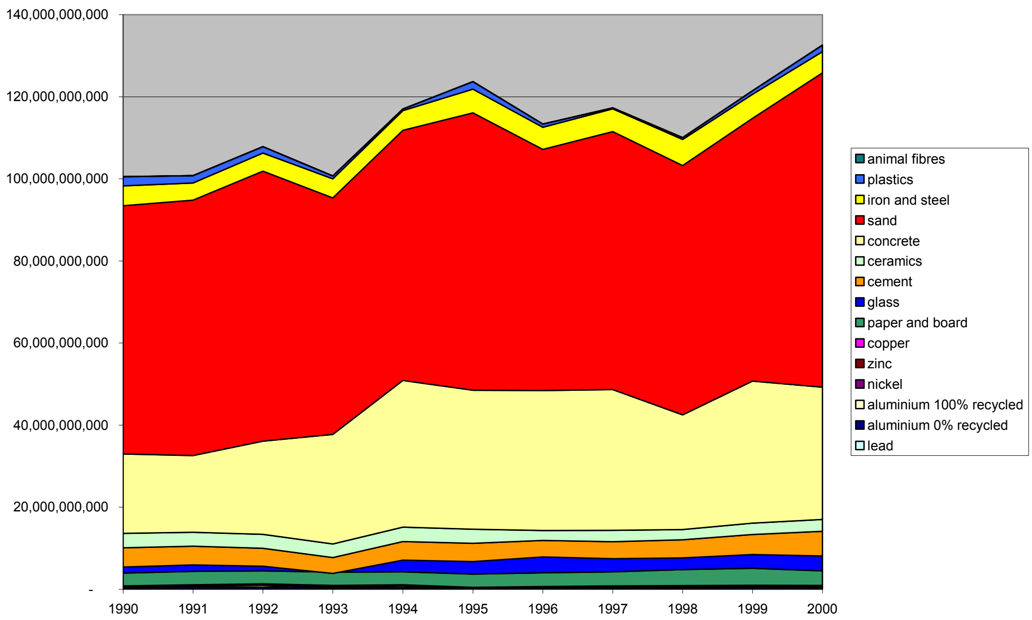


figure 23 Trends in kilogram consumption of 14 materials *sensu stricto* in the Netherlands, 1990-2000



As figure 21 shows, agricultural materials make up about one-fifth of the total volume flowing through the Dutch economy, while construction materials account for the greatest share. Within the group of food-related materials, starch crops and animal fats have the largest flows, as can be seen in figure 22. Figure 23 shows the flows in a little more detail. Metals can scarcely be distinguished, with construction materials contributing about 90% to the overall picture.

Based on these empirical trends, the first conclusion to be drawn is that in the Netherlands, at any rate, there has been no dematerialisation (in absolute terms). In fact, between 1990 and 2000 kilogram consumption rose overall by almost 30%. This is particularly true of materials *s.s.* and seems to be due mainly to sand. The increase from 1999 onwards is attributable partly to site development for the IJburg construction project, which required vast amounts of sand. Major transport infrastructure projects like the Betuwe rail freight link and the coastal high-speed link were also major consumers of sand.

A second conclusion is that consumption trends are fairly erratic. In the case of agricultural crops, year-to-year variation will naturally depend very much on harvest quality, which is subject to the fluctuating whims of the weather. In the case of materials *s.s.*., this may on the one hand be due to the pattern of economic growth: particularly in the years following a recession, materials use may rise quite steeply as the economy picks up again. This may explain the peak in 1995, following the recession of the early '90's. This is because many industries then embark on a cycle of expansion, with an attendant increase in construction activity and consumption of all the materials that entails. A second reason may derive from the notion of apparent consumption itself, which is calculated by deducting exports from production plus imports. Changes in stockpiles may then render the overall picture more erratic than it in fact is: if large quantities of steel are produced in a given year but stockpiled for sale the next, this creates the impression of elevated steel consumption the first year followed by depressed consumption the next. Because trade flows are governed above all by the stock market (via the London Stock Metal Exchange, for example) a batch of steel may be sold before it has even been produced. This obviously makes for erratic trends.

4.3 Environmentally-weighted Materials Consumption

The next step is to multiply these apparent consumption figures by per-kg impacts, yielding an indicator providing information on environmentally-weighted materials consumption (EMC). The resultant EMC time series will differ from the series for volume consumption, with other materials now gaining in prominence.

This exercise can be carried out for each individual environmental impact theme, hopefully yielding valuable information on the theme in question. It can also be done across all themes, using one of the weighting methods discussed in Chapter 3.

Figure 24 shows trends in EMC for all 21 materials, based on equal weighting of all 13 impact categories. As can be seen, there was an overall increase of about 17% between 1990 and 2000. The picture is erratic, though, with a clear peak in 1996.

figure 24 Impacts of Dutch materials consumption, 1990-2000 (equal weighting)

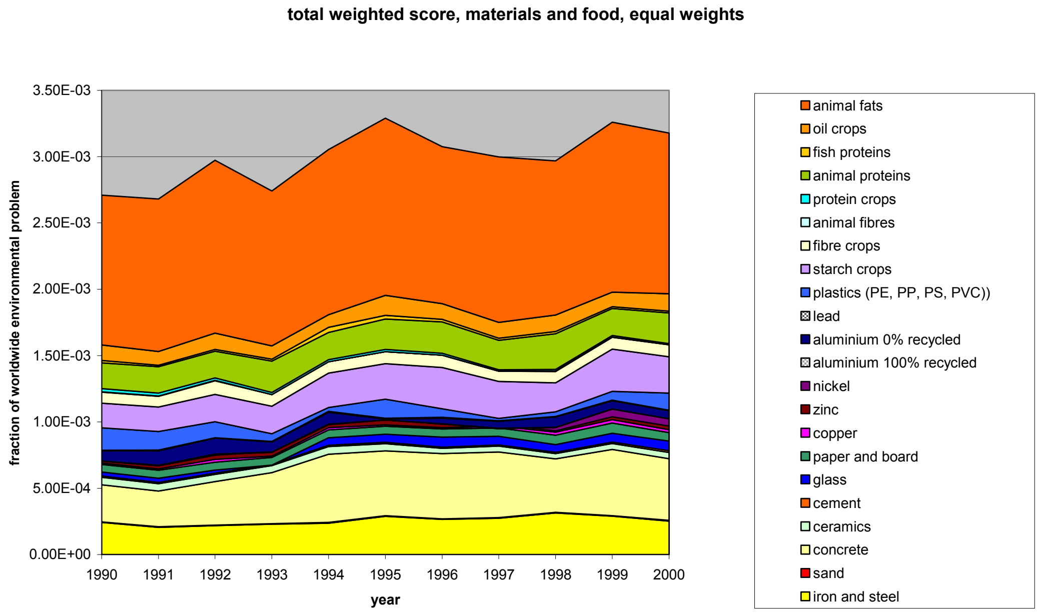
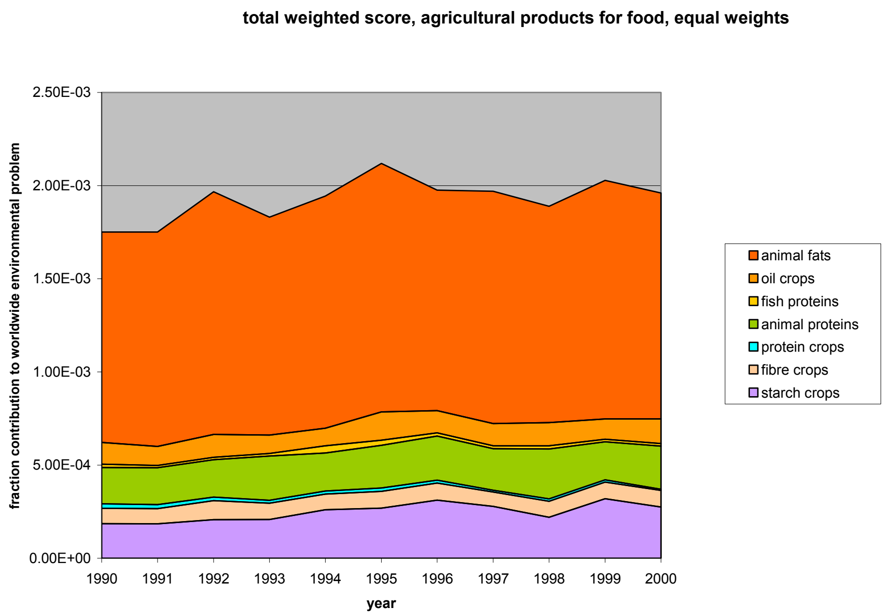


Figure 25 also shows that the food-related materials in this case account for over half the overall score. The per-kg impacts of these materials are, in other words, high compared with other materials.

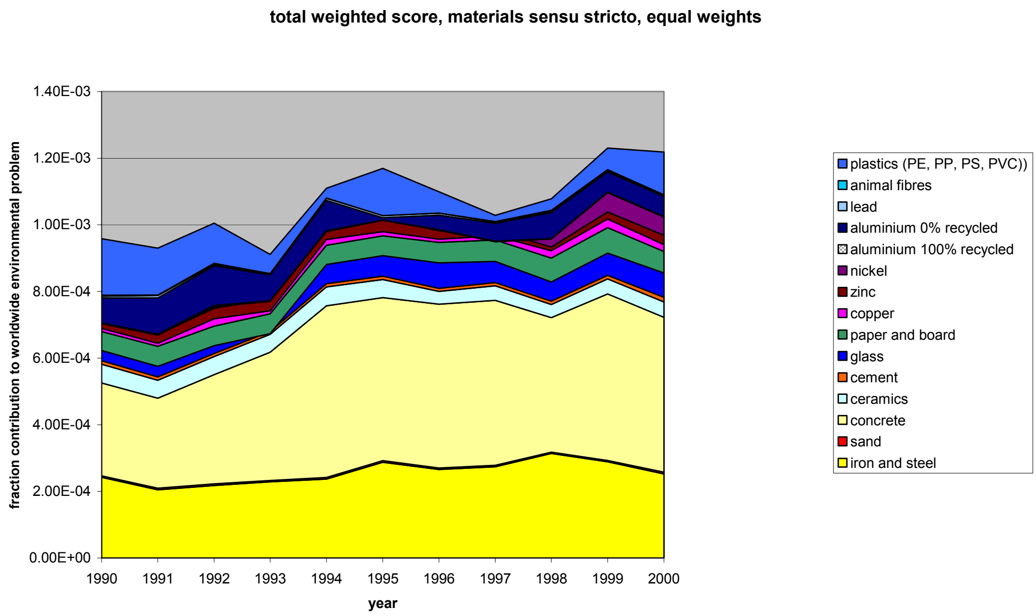
figure 25 Impacts of Dutch materials consumption: food-related



Animal products feature prominently. That was already the case with consumption, but the effect is heightened by the high per-kg impact of these materials. Figure 25 clearly shows that the peak in 1996 is due above all to a peak in production of animal fats. Between 1990 and 2000, the EMC for food-related materials rose by a modest 10% or so.

Trends in the other materials are more erratic (figure 16). This is probably related to the use of ‘apparent consumption’ data, as mentioned in the previous section. The impact of plastics, in particular, fluctuates considerably, which may in this case be due to data problems (see Appendix D). Between 1990 and 2000 there was a 27% increase in the EMC for materials *sensu stricto.*

figure 26 Impacts of Dutch materials consumption: materials s.s.

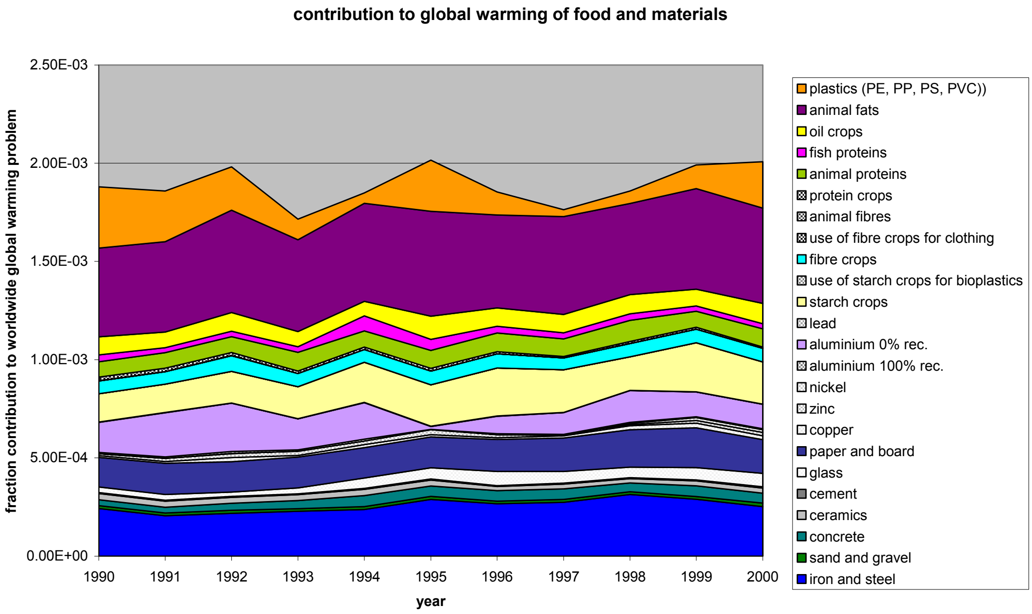


After weighting with per-kg impacts, the share of construction materials falls substantially, with only concrete staying fairly high on the list. Sand, a major flow in tonnage terms, is now scarcely visible because of its extremely low per-kg environmental impact. Metals, volume consumption of which was modest, now feature far more prominently.

4.3.1 Further analysis: a single environmental theme

Instead of the aggregated indicator examined above, an indicator can also be calculated for one specific environmental theme. This may be important if the idea is to use material flow policy to address one individual theme. As an example, figure 27 shows trends in the EMC for Global Warming.

figure 27 Impacts of Dutch materials consumption, 1990-2000: global warming

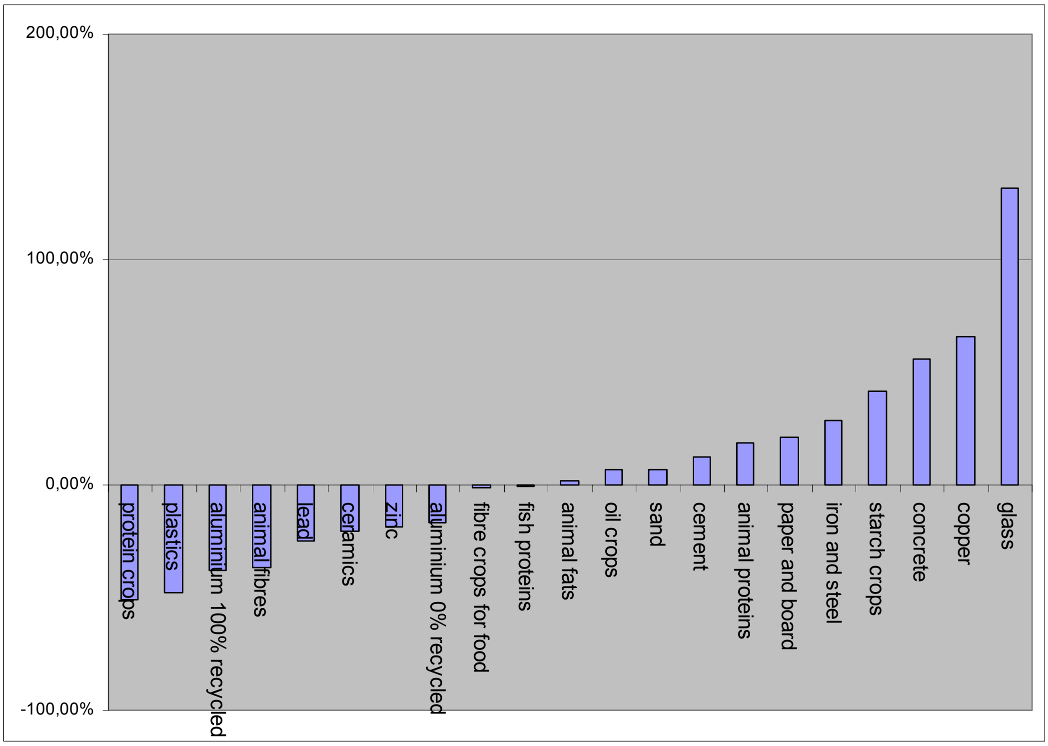


Metals and agricultural crops score high on global warming. Despite the relatively small quantity involved, fish also shows up in the chart. Construction materials, dominant in tonnage terms, are seen to make little contribution to global warming. In addition, nothing much remains of the rise in materials consumption noted in the previous section: between 1990 and 2000 the indicator was basically in a state of flux, with no clear trend visible.

4.3.2 Further analysis: EMC per material and per unit GDP

As the above analysis shows, between 1990 and 2000 EMC increased overall by 17% and the weight (apparent consumption) of the 21 materials by over 30%. During the same period Gross Domestic Product (GDP) rose by 33%. It can therefore be said that although there does not appear to have been any decoupling between volume consumption of these materials and GDP, there was between their environmental impact and GDP. This suggests that there was less volume growth of materials with a high environmental impact and more growth of lower-impact materials. Figure 28 shows the increase or decrease in Dutch consumption of the 21 materials between 1990 and 2000.

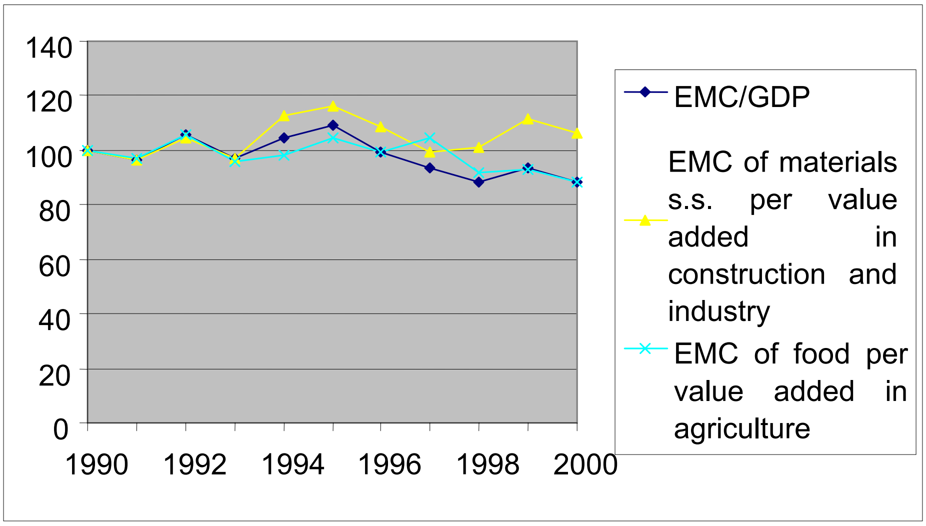
figure 28 Trends in Dutch materials consumption, 1990-2000



As the figure shows, the greatest increase in volume consumption was for glass, while consumption of zinc, lead and aluminium showed a marked decline, as did that of several food crops. The decline in aluminium consumption is probably due to closure of the Fokker aircraft plant during this period.

Overall trends in EMC per unit Dutch GDP (in 1995 prices) are shown in figure 29. The first thing to note is the downward trend since 1995, implying that the materials efficiency of the Dutch economy has been improving. There are a number of possible reasons for this, varying from structural changes to the economy to a wide range of technological innovations in production systems. If we restrict ourselves to the EMC per Euro value added for food crops, there is still decoupling. The EMC for food crops has been indexed to the added value of the Dutch farming sector because consumption of many food crops is tied up with the Netherlands' large livestock farming sector. Although the basic EMC for food crops rose far less sharply than total EMC, it can now be seen that per unit GDP the trend for the farming sector does not essentially differ from overall EMC/GDP. The EMC for materials *s.s.* has been indexed to the added value of construction and industry, these both being major consumers of finished materials. With this indicator there proves to have been no decoupling, EMC keeping abreast of the added value of these two sectors. This may be an indication that no progress has been achieved in construction and industry when it comes to materials substitution, dematerialisation and use of recycled materials for product manufacture. These conclusions are in line with earlier analyses [De Bruyn & Opschoor, 1997]; [Hoekstra, 2003] demonstrating the lack of any trend towards dematerialisation in the Netherlands for a wide range of materials. In this respect the Netherlands is at variance with other European countries, where such a trend has indeed set in in recent years.

figure 29 Trends in EMC materials efficiency, index figures (1990 = 100)



4.4 Further use of the indicators: life cycle analysis

The EMC developed here need not only be used at an aggregated level. The great advantage of an indicator of this kind is that it can also be used for individual materials and that combining volume consumption with Life Cycle Analysis results can yield additional information of relevance for material flow policy. It may, for example, provide more insight into the phases of the life cycle where policy efforts can best be directed. In this section we look more closely at this use of the proposed indicator.

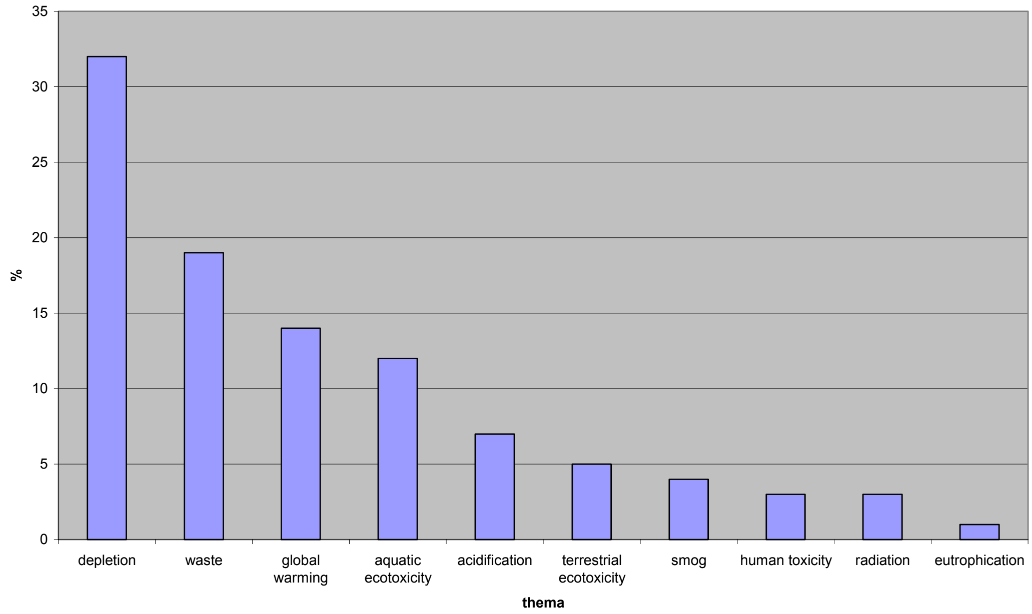
For several materials we examined the exact make-up of the overall environmental impact score. The materials selected were: concrete, animal products from livestock farming and steel. For each of these materials we first looked at the shares of the various environmental themes in the total impact score, obtained, it will be remembered, by equal weighting of the 13 impact themes. We then determined which phases of the life cycle / supply chain contributed most to each. Finally, we identified the specific emissions and extractions responsible.

The main aim of this exercise is to illustrate how the methodology plays out when specific materials are analysed, rather than paint a distinct picture of how damaging the materials are. The motive is to enhance understanding of the methodology adopted in this study and suggest possible improvements for the future.

Steel

Figure 30 shows the share of selected environmental themes in the overall impact score of steel.

figure 30 Steel: share of environmental themes in overall impact score for Dutch consumption (2000)

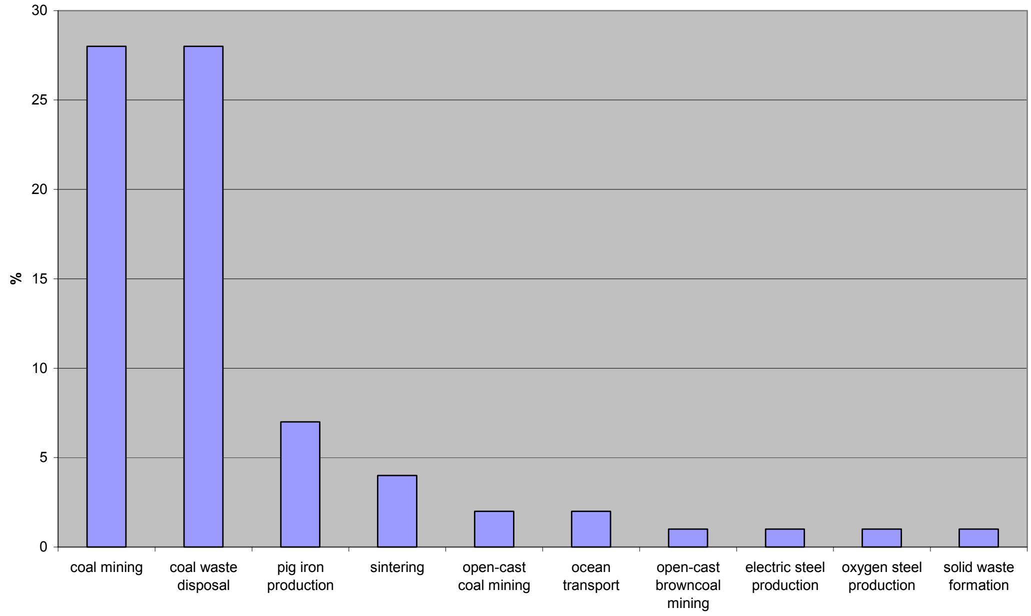


As can be seen, the greatest problem with steel appears to be depletion (i.e. abiotic resource depletion). This is in line with the LCA database methodology, but it may be argued that the 'depletion' of steel (and the raw materials from which it is produced) is not so much an environmental issue as an economic one[24]. Besides depletion, waste, global warming and freshwater ecotoxicity also make a sizable contribution to the overall score, and in these cases we are concerned with true environmental problems.

Figure 31 shows the respective shares of supply chain processes in the overall impact score for steel.

[24] For this reason, in future work it might be opted to include depletion only in the case of renewable resources, setting the depletion indicator to zero for non-renewables.

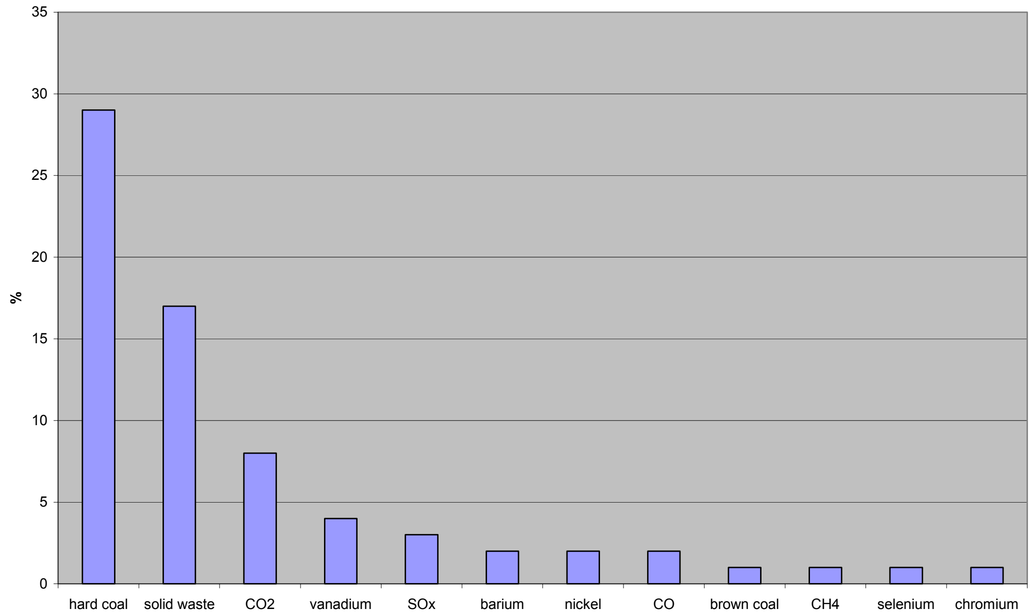
figure 31 Steel: share of individual processes in overall impact score for Dutch consumption (2000)



It is immediately apparent from the figure that coal-related processes account for the bulk of the overall impact score, with pig iron production and sintering also making a modest contribution. All the other processes are relatively insignificant.

Figure 32, finally, provides a breakdown of the impact score in terms of contributing flows, i.e. extractions and emissions.

figure 32 Steel: share of flows (extractions and emissions) in overall impact score for Dutch consumption (2000)



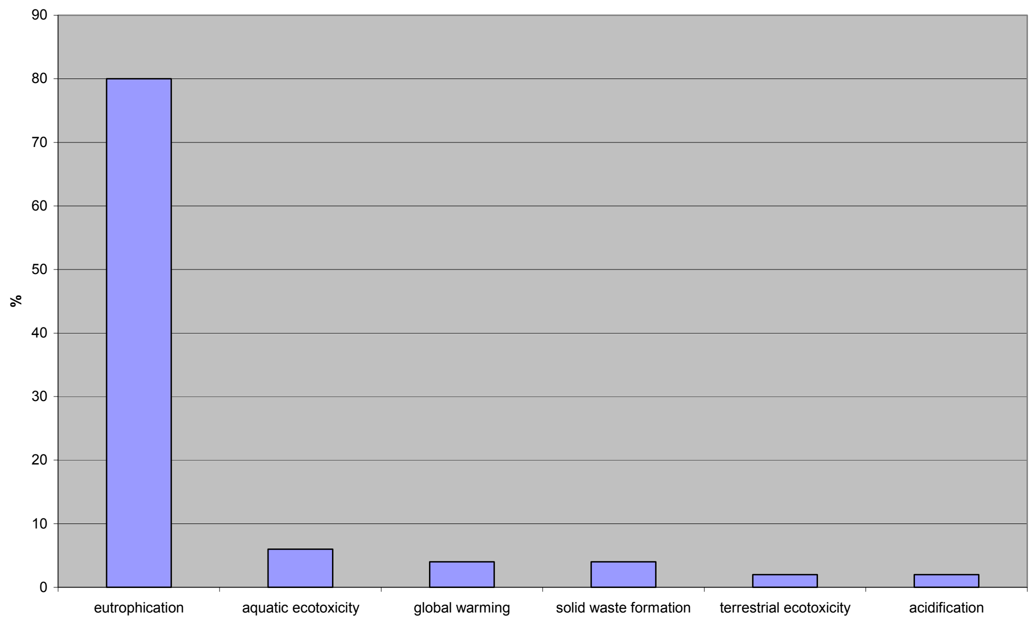
Again, coal proves to contribute most to the overall environmental impact. The high score here is also connected to resource depletion. The solid waste flow is also due to coal mining, as are the various metal emissions. CO_2 also comes into the picture, with these emissions arising mainly during pig iron production and sintering. SO_x and CO also contribute a few per cent. These emissions occur during sintering, oxygen steel production and ocean transport.

The use of coal (coke) for steel production is thus responsible for a major share of the environmental impacts associated with steel. This might prompt policy-makers to recommend that alternative fuels be sought, for example subcoal (a plastics-based coke substitute). At the same time it is also important to distinguish between primary and secondary materials. As a rule, far less raw material is required for the production of secondary steel. The database works with a fixed ratio of primary to secondary steel, however, making it difficult to distinguish between the two in terms of environmental impact as well (in contrast to aluminium). This kind of exercise thus not only identifies leverage points for life cycle-oriented material flow policy, but also points to the limitations of the method as well as the database. In doing so, it suggests one of the directions for further research.

Animal products

Figure 33 shows the contribution of the various environmental impact themes to the overall score for animal products (again based on equal weighting).

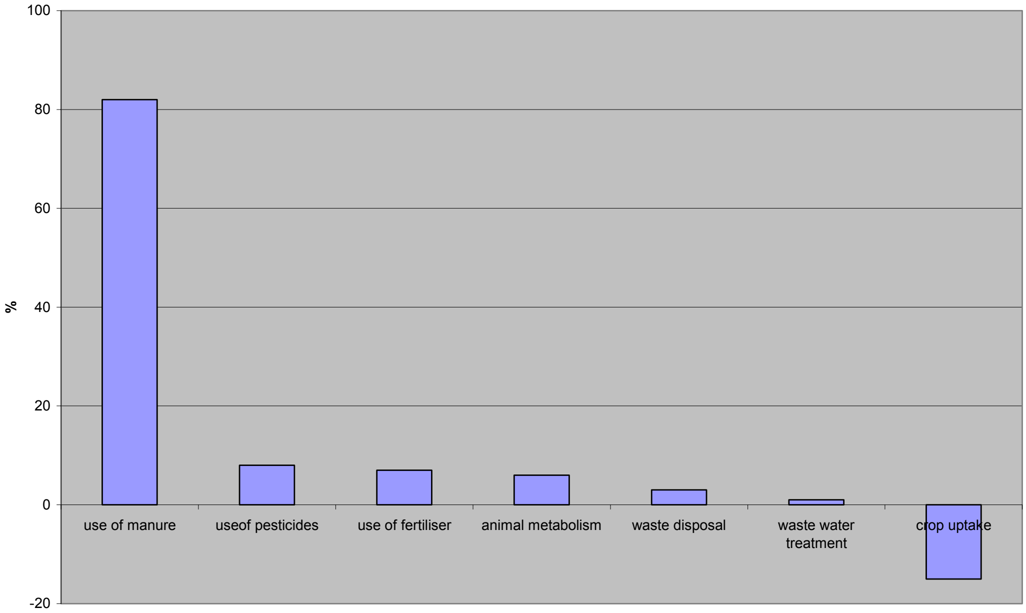
figure 33 Animal products: share of environmental themes in overall impact score for Dutch consumption (2000)



As can be seen, eutrophication is by far the most important environmental impact, accounting for 80% of the overall score. Each of the other themes are responsible for only a few per cent.

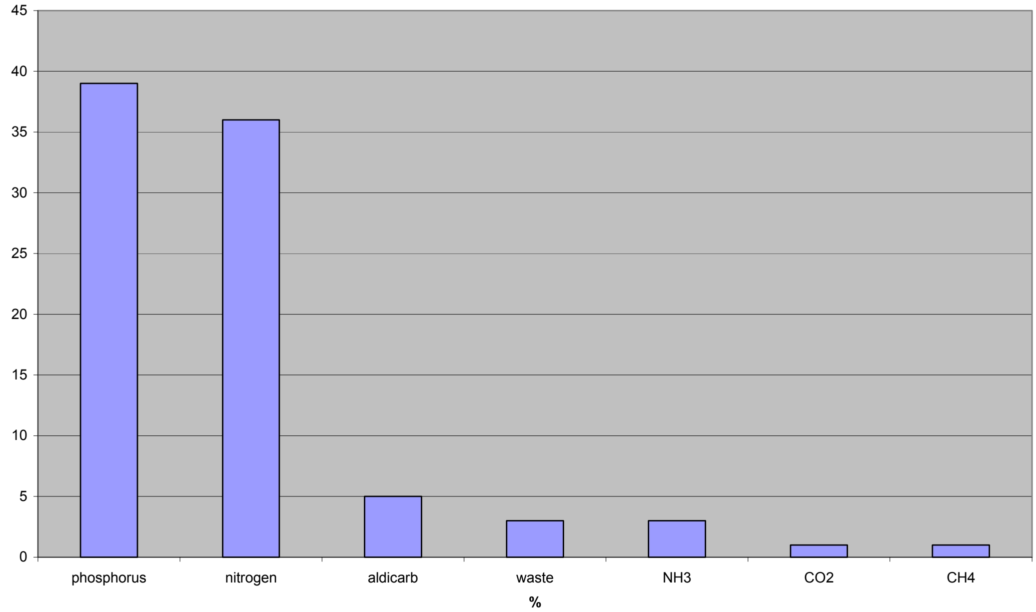
Figure 34 shows the share of individual processes in the overall environmental impact associated with animal products.

figure 34 Animal products: share of individual processes in overall impact score for Dutch consumption (2000)



As is to be expected, it is above all manure use that predominates in the overall picture. The contribution of animal digestion is also noteworthy. The uptake of nutrients and CO_2 by crops leads to a negative score on this item; in other words, this partly offsets the other problems.

figure 35 Animal products: share of flows (extractions and emissions) in overall impact score for Dutch consumption
(2000)



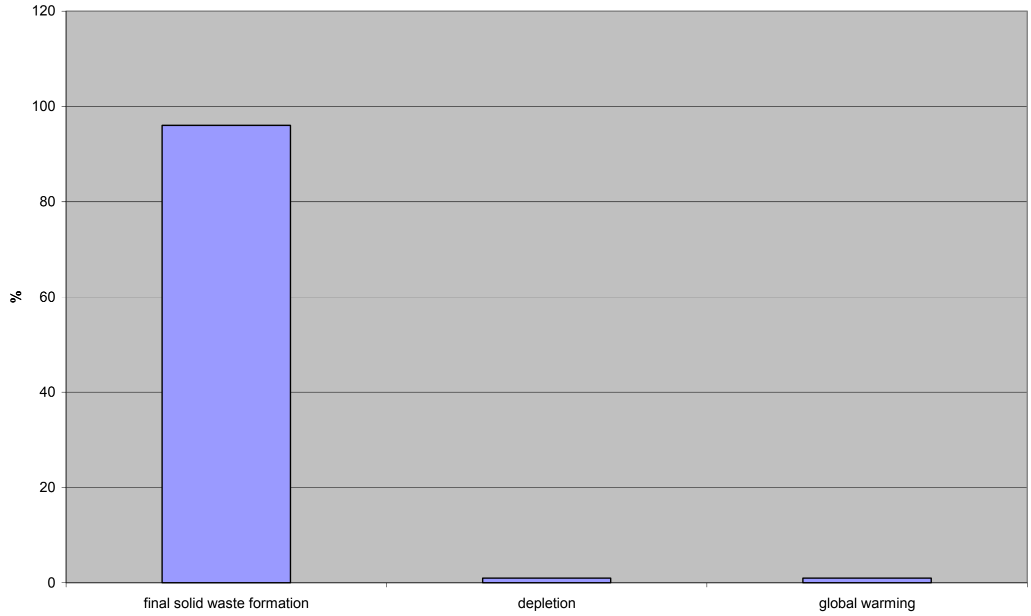
Phosphorus and nitrogen from manure and artificial fertilisers together account for about three-quarters of the overall score. NH_3 and CH_4 are excreted by farm animals, as is some of the CO_2. The rest of the CO_2 arises in the wastewater treatment process that forms the 'grave' of the life cycle. This is largely offset by the CO_2 uptake in the 'cradle' phase, reducing the overall net contribution of CO_2 to quite a small percentage. Aldicarb, finally, is a commonly used and extremely toxic pesticide and this also shows up clearly in the results.

For policy-makers it is of interest to know that a substantial part of the overall score is due to phosphorus and nitrogen. These substances are already specifically addressed by national policy on manure, and a dedicated material flow policy for these particular materials would therefore seem unnecessary. What might be concluded, however, is that policies to reduce these emissions can never be truly successful, because of the inherent inefficiency of meat and animal product production, with most of the inputs (animal fodder) ending up not in the product but in the final waste (manure) of the process. The main 'valve' to be shut off is therefore at the end of the chain: consumption of these products.

Concrete
With equal weighting of impacts, concrete appears to qualify as an important material in environmental terms. Analysis of the respective shares of impact themes in the overall score (figure 36) shows, however, that the score is due almost entirely to final waste, which in turn hinges on the assumption made regarding final waste disposal at the end of the life cycle, *viz.* that the entire influx of concrete to the system is ultimately landfilled as waste. In actual fact, though, most concrete is recycled. Unfortunately, the LCA method assumes a steady state that makes no allowance for 'stockpiling' by society (in engineering works,

buildings and so on) and accounts only indirectly for recycling. The assumption made in the present study is not ‘wrong’, to the extent that every input to the economy will indeed eventually leave it as output. Recycling is then indirectly visible, as less demand for new concrete, something that is reflected in the flows charted. Because of the provisos and caveats regarding the assumptions on waste disposal and because of perhaps justifiable doubts about the importance of final waste disposal as a true environmental impact, the results of this analysis are not particularly interesting.

figure 36 Concrete: share of environmental themes in total impact score for Dutch consumption (2000)



For this reason we redid the analysis, now limiting ourselves to the ‘cradle-to-gate’ part of the chain, i.e. excluding consumption and waste disposal. The results are shown in figures 37, 38 and 39 for impact themes, process and flows, respectively.

figure 37 Concrete: cradle-to-gate score for Dutch consumption (2000)

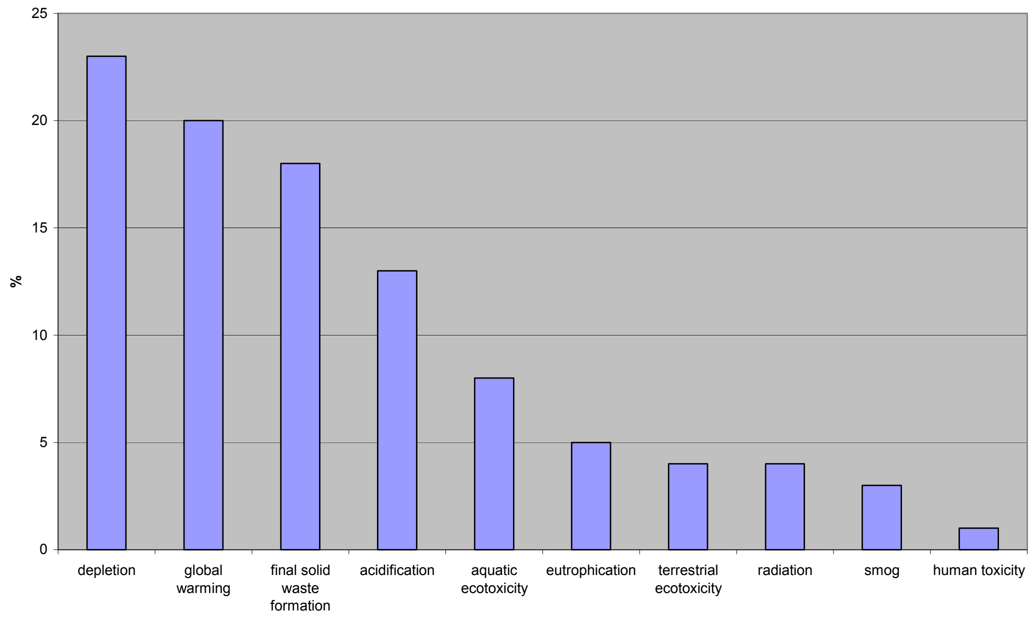


figure 38 Concrete: share of individual processes in cradle-to-gate score for Dutch consumption (2000)

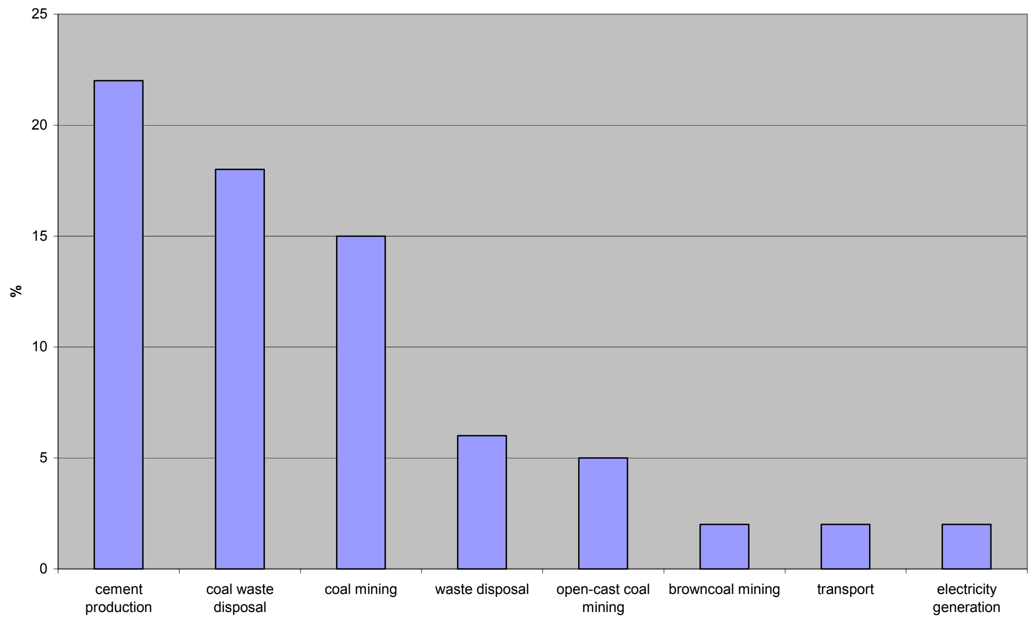
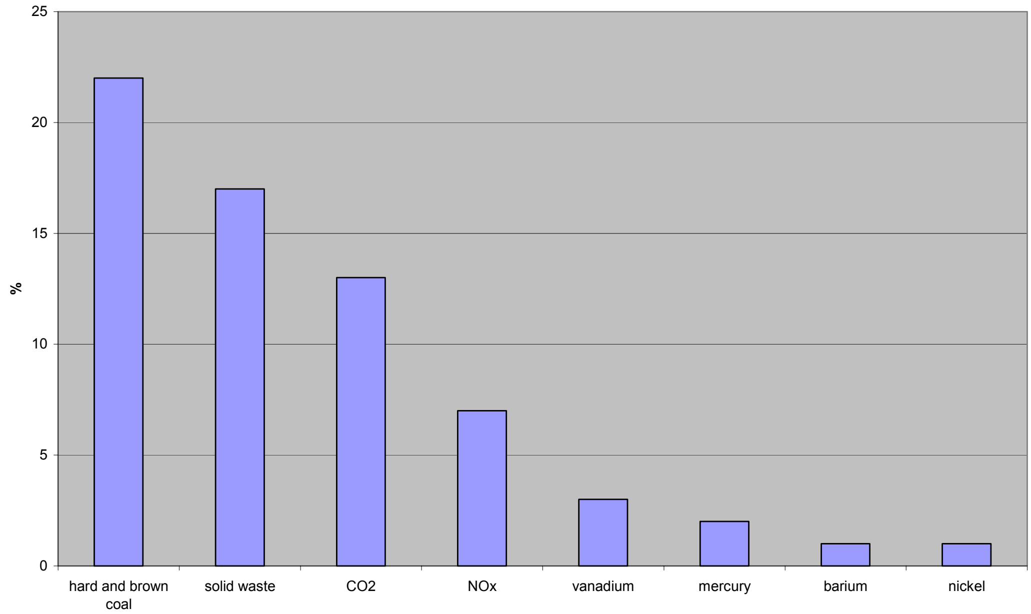


figure 39 Concrete: share of flows (extractions and emissions) in cradle-to-gate score of Dutch consumption (2000)



Once again, depletion is a major contributor to the overall score, attributable mainly to coal mining. Even if we restrict ourselves to production, final waste remains important. We are here concerned with industrial waste from cement production and mining waste. Again, some of this may be queried. There is little coal-burning involved in Dutch cement production, with gas firing and increasingly co-firing of refuse being used for the process. The LCA database is thus on the one hand not specific enough for the Dutch situation - of particular importance for construction materials, as discussed earlier - and on the other hand probably outdated. The relevance of resource depletion as an impact theme in Dutch environmental policy is also debatable, it may be added, many people holding this to be an economic rather than environmental issue.

Emissions of greenhouse gases, which are indeed behind a major environmental problem, occur mainly during cement production. These emissions arise partly from fuel-burning and partly from the calcareous rock itself. This latter fraction is unavoidable and can only be reduced through capture and sequestration. NO_x emissions, again during cement production, are the main contributor to acidification. The emissions of toxic metals are associated mainly with the disposal of coal mining waste.

In the Dutch situation, where coal is no longer used as fuel, this would mean that concrete does not perhaps deserve the highest policy priority as a material. With these results in mind, it is also to be queried whether equal weighting of the impact themes leads to the right priorities being set. What this exercise at any rate demonstrates is that for relatively high-scoring materials it is worth taking a closer look at how that score is made up. This will provide insight into opportunities for improvements up and down the supply chain, but also highlight inaccuracies and errors in the database and the importance of how the various environmental impacts are weighted relative to one another.

4.5 Conclusions

1. Materials deriving from agriculture are responsible for a major share of the overall environmental burden; this is particularly true of animal products.
2. Construction materials are used in vast quantities, but have comparatively little environmental impact.
3. For metals, the opposite is true: although used in relatively small quantities, they have a substantial environmental impact.
4. Indicator trends are erratic. This is due to irregularities in volume consumption data. These may be the result of statistical errors, for example in the used concept of apparent consumption, although this has not been proved.
5. In the period reviewed there was an upward trend in the indicator for all the materials. The increase was most pronounced for materials *sensu stricto*, in both absolute and relative terms (i.e. per unit GDP). This suggests that the construction sector and the industries consuming the finished materials have not yet made much progress on dematerialisation, materials substitution and/or use of recycled materials in their products.
6. The LCA database has its limitations, due to its ‘steady-state’ approach, which means that improved technologies only show up in the results when a new update of the database is released. In some cases average West European data are not representative for the Dutch situation.
7. LCA databases may be useful for establishing what exactly is responsible for the environmental impact of a particular material, often permitting identification of key areas for policy leverage. This may also give a better picture of the value of the process data for the Dutch situation.
8. In a future version of an EMC indicator, environmental impact themes need not be weighted equally, but according to relevant environmental policy targets, shadow prices or damage cost, for example. Whatever the case, it is recommended to consider abiotic resource depletion mainly as an economic rather than an environmental problem and correct the LCA impact factors for depletion accordingly.

5 The materials perspective in current policy

5.1 Introduction

In the previous chapters we have demonstrated the feasibility of constructing an indicator measuring the environmental impact of the materials provisionally characterised as being most environmentally damaging in the Dutch context.

However, demonstration of feasibility in itself tells us nothing about how such an indicator is to be employed in the context of an economy-wide material flow policy. In the 4th National Environmental Policy Plan (NEPP4), for example, it is stated that any new material flow policy must, above all, *supplement* standing policy. To align ourselves explicitly with NEPP4, in this chapter we identify those areas in which some form of materials policy is already in place in the Netherlands. The sole purpose of this chapter is thus to review standing policy, with no conclusions immediate forthcoming as to how additional policy might best be shaped or how an economy-wide material flow policy might serve to integrate existing policies. At the same time, though, it may be useful to review whether all the options for reducing the environmental impact of material flows are being sufficiently utilised at present.

First, in section 5.2 we discuss some methodological principles. Next, in sections 5.3 to 5.5, we systematically examine three categories of current materials policy: sectoral policy, product policy and raw materials policy. Section 5.6 concludes with an interpretation of the results.

5.2 Scope and methodology

5.2.1 Policies included in the review

For the selected group of materials *sensu stricto* assessed in the previous chapter, in this chapter we review all standing Dutch policies of relevance, i.e. policies having any of the three key impacts cited in section 2.2.3:

1 Dematerialisation: materials savings and increased resource productivity, i.e. less materials used per 'functional unit'.
2 Materials substitution: replacement by an alternative having less net environmental impact.
3 Recycling, using secondary rather than primary materials from the same or a different supply chain.

Dematerialisation, substitution and recycling all directly affect the composition and magnitude of material flows and thus also their environmental impact. In line with the scope delineated in section 2.2.3, we here ignore any policies with a possible impact on the emissions occurring during materials production or use. Nor does the review include policies involving energy recovery as a form of 'useful application'[25]. After all, in terms of materials use this only affects the consumption of fossil fuels, which have been excluded from the present study. In contrast, economically beneficial application of waste materials in other supply chains (blast-furnace slag in cement production, for example) is here categorised as 'reuse'.

This policy review covers existing Dutch policy as well as EU directives having implications for the Netherlands (now or in the near future), but gives no consideration to policies presently on the drawing board.

Individual policies can impinge on materials consumption both directly and indirectly. They may also have both intentional and unintended effects.

Effects are direct if a policy is explicitly designed to steer the composition or weight of the flow in question. If recycling targets are set for packaging, for example, there will be a direct and intentional effect on recycling rates. A road tax differentiated according to weight because heavier vehicles cause greater wear and tear to road surfaces will have a direct but unintended effect on the quantity of materials used in road vehicle manufacture.

Effects are indirect if the policy has an impact on materials consumption by a roundabout route. This holds for fuel excise duty and the Regulatory Energy Tax, for example, which may have an indirect - though partly intentional - effect on vehicle weight or the design of electrical equipment. Another example of a policy possibly impacting indirectly on materials consumption is vehicle circulation tax, which is differentiated according to vehicle age. Such policies with an indirect effect are *not* included in the following review. In the case of policies with direct effects, it will be indicated whether or not these are indeed intended.

[25] The EMC indicator does incorporate the impact of such policies, however.

5.2.2 Materials included in the policy review

As stated, the materials examined here are the 14 selected for inclusion in the indicator for the group of materials *sensu stricto.* These are listed in table 4.

table 4 The 14 materials reviewed, with their main applications

Material	*Applications*
Steel	construction, automotive, white & brown goods, packaging
Aluminium	automotive, construction, foil, packaging
Copper	water pipes, cables, electronics
Nickel	stainless steel
Zinc	zinc plating, brass, roof gutters
Lead	batteries, chemicals
Concrete, cement, sand	construction
Ceramics	construction (brick, tiling), engineering (electronics)
Paper and board	packaging, graphic
Plastics (incl. rubber)	construction, automotive, electronics, tyres, packaging, engineering
Glass	packaging, construction (plate glass)
Animal fibres	carpets, clothing

We opted not to undertake a systematic policy review on food crops, for two reasons. In the first place, food-related policies play out in a different policy setting in which considerations other than environmental play a key role (food safety, for example). Secondly, the supply chains and life cycles involved deviate in several important respects from those for other materials (and fuel resources). ‘Reuse’ of food as such is out of the question, the notion of ‘dematerialisation’ is not applicable, and the scope for substitution is only limited. Possible substitution impacts include reuse in a different supply chain - as a secondary fuel, for example - and direct substitution, as in the case of environmental labelling schemes. The latter may be the case when there is a switch to Eco-label agricultural produce; although there is no ‘new’ material involved, the materials used are more benign.

There is a similar kind of impact with FSC-certified wood. Although wood, too, is not among the materials included in the present review, the FSC certificate for sustainably produced wood may have some influence on the 14 materials selected, wood being used as a raw material for paper and board (although the market share of sustainably produced wood pulp is still minimal according to FSC[26]) and as an alternative for several building materials (particularly in the DIY and road and waterway engineering sectors). These latter materials are included in the selection reviewed here.

This type of substitution we term ‘profile substitution’ to distinguish it from ‘materials substitution’. In our view, it is only with biotic materials that ‘eco-certified’ varieties differ sufficiently from ‘non-certified’ for there to be true profile

[26] *‘FSC in de markt: De beschikbaarheid van FSC-gecertificeerd hout op de Nederlandse markt 2000-2003’,* November 2002.

substitution and for this to additionally be the main impact of using them[27]. Another possible example of profile substitution is replacement of conventional by biotic materials, as with bioplastics or other biomass-based chemicals, which are being promoted by the ministry of economic affairs as part of the 'transition' strategies towards sustainability. It should be noted, though, that this kind of profile substitution, like materials substitution, does not necessarily lead to environmental gains.

5.2.3 Methodology

To align ourselves with the conventional policy classification scheme, in this chapter we distinguish three kinds of policies, according to the link in the chain where policy leverage is exerted:

1 Sectoral policies: what policies addressing individual sectors (e.g. basic metals, waste disposal, packaging) affect materials consumption? *This is mainly national waste policy, negotiated agreements ('covenants'), subsidies, etc.*

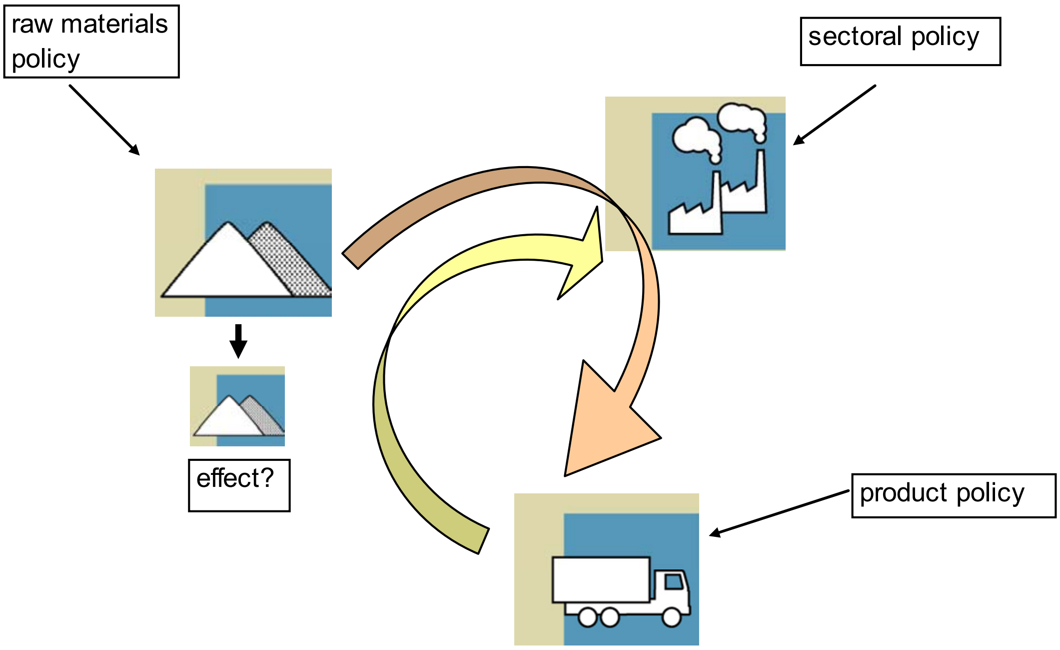
2 Product policies: what policies addressing products (generic, as with Integrated Product Policy, or specific, as with cars, electronics, etc.) affect materials consumption? *These are mainly taxes, manufacturer and retailer 'take-back' obligations, labelling schemes, etc.*

3 Raw materials policies: are there policies that directly address the use of certain raw materials in the production process? *These are mainly taxes, bans, etc.*

This is shown schematically in figure 40. The quantity of raw materials fed into the economy can be reduced by exerting policy leverage at any point in the chain, from extraction via production and use through to final waste and recycling.

[27] Profile substitution can be regarded as a kind of product policy; in the case of food resources, this would seem a promising strategy for reducing environmental impact.

figure 40 Policy leverage on links in the materials processing chain



For each of these leverage points we shall first assess the extent to which standing policies impact on dematerialisation, substitution and recycling. Our aim here is not to attempt a comprehensive analysis, but rather to gauge the approximate magnitude of any effects and which element(s) of the overall material flow are affected by the policy in question. In this chapter these effects will be discussed mainly in qualitative terms. Together, these estimates will eventually provide an impression of the impact of current Dutch policy on each material flow as a whole.

The national Waste Management Programme (LAP[28]) fulfils a pivotal role in the policy framework reviewed in this chapter. Under the terms of this programme, a series of plans have been drawn up for specific sectors, addressing a great many waste streams and concerned with both reuse/recycling ('useful application') and prevention. In this respect, both the LAP and the sectoral plans have an umbrella function for the waste streams of interest here. These various policies have been implemented using a broad range of instruments not necessarily ensuing from the LAP but, rather, integrated within it. Besides a number of European directives[29], this includes the Building Decree and various negotiated agreements, known as 'covenants' in the Netherlands.

Although the following review covers the policies as well as the sectoral plans, these will have partly the same effects. This will then be indicated accordingly in the summary tables of results.

[28] As we are concerned in this chapter specifically with Dutch policies, after providing a brief description we have opted to refer to them by their Dutch acronyms.

[29] Waste Framework Directive, Hazardous Waste Directive, Batteries Directive, Packaging Directive, Landfill Directive.

5.3 Sectoral policy

Sectoral policy addresses (groups of) producers, mainly at the level of basic industries, regarded as the link of the supply chain having the greatest overall environmental impact (see analysis in section 4.4) and therefore providing a good measure of policy leverage.

Besides these sectoral waste policies, this section also identifies several wider policies with a potential impact on materials consumption, *viz.*:
- 'Environment and Industry' policy (DMI).
- Second Long-Term Agreements on Energy Efficiency (MJA-II).
- Substance-specific policy (SOMS).

5.3.1 Sectoral waste policies

Specific waste policies are in place for the following sectors: Construction & Demolition, Packaging, Plastics, Textiles, Metals, Industry and Office, Shop & Service (OSS). Many of these have been implemented under the LAP umbrella, sometimes backed up by more dedicated policies on specific material flows.

Appendix J reports the policies in force in each individual sector, summarised here in table 5.

table 5 Analysis of sectoral plans

Sector	Policy framework	Main effects	Quantitative target ?
Textiles	LAP	Recycling	Yes
Metals	LAP (Sectoral plan 21)	Recycling	Yes, for tins
Chemical industry (plastics)	LAP, landfilling bans under Waste Substances (Prohibition of Landfill) Decree	Recycling	Yes, for agricultural & horticultural sheeting
Paper & board	LAP/3rd Packaging Covenant	Recycling	Yes, via packaging
Industry	LAP, process-related industrial waste	Substitution, dematerialisation	Yes.
OSS	LAP, General Administrative Orders	Unknown	?
Packaging	EU Directive 94/62/EG, 3rd Packaging Covenant	Recycling, dematerialisation. Unintended effect: substitution	Yes.
Construction and demolition	LAP, Building Materials Decree, Regulation on non-recyclable and non- incinerable construction and demolition waste; Landfill Decree; DuBo programme	Substitution, recycling, profile substitution	Yes, mainly regulations and bans

As this table and the more extensive review of Appendix J show, the main policy leverage is on recycling. This is not that surprising, as sectoral policy in this case is no more than waste policy. There is also some promotion of substitution, though, particularly in the construction industry. Thus, the Building Decree provides incentives for using more environmentally benign materials. The 'DuBo' scheme (now to be discontinued) also promoted profile substitution in the form of higher-quality varieties of wood, concrete and plaster. The sectoral plan for process-related industrial waste has also sought to improve the materials efficiency of industrial processes and thus reduce materials input, which might effectuate some degree of dematerialisation.

Dutch waste policy has ambitious separation targets for 2006 for the various categories of waste, shown in table 6 along with current separation rates.

table 6 Waste separation rates and targets (source: *Afval Overleg Orgaan*: www.aoo.nl)

Material / product	Situation 2001 / 2002	Target for 2006	Mode of separation
White and brown goods	90	90	Via retailers / council
Hazardous Household Waste	70	90	Via retailers / council
Paper and cardboard	67	75	Via collection points
Tins	78	80	Mechanical separation
Glass packaging	70	90	Via bottle banks
Textiles	~30	50	Via clothing collection points

The issue of what happens to this waste *post*-separation is not considered in the present study. Some of the separated waste is in fact exported and does not therefore lead to any more use of secondary materials by the manufacturing industry. Except in the case of the construction industry, though, there are no policies explicitly addressing this latter issue. Consequently, policies promoting waste separation do not necessarily lead to increased reuse and recycling, although in practice this is probably their main effect, with some degree of (profile) substitution also occurring.

→ Main effects: recycling, substitution

5.3.2 General industry policy

'Environment and Industry' policy

Under the 'Environment and Industry' policy (DMI) 11 industrieal sectors have been set a number of emission reduction targets for 2010. Although more qualitative in nature, agreements are also in place on waste disposal, soil remediation, water consumption and environmental management systems. DMI targets the following industries: basic metals, paper & board, glass, plastics & rubber, and textiles & carpeting. It is only the agreements on waste disposal, with their percentage targets for recycling rates and/or useful application, that may have some influence on materials consumption.

With respect to process-related waste, the agreements have been reached under the terms of the LAP Waste Management Programme, with quantitative targets established in negotiated agreements under DMI. These DMI agreements and the LAP sectoral plan are thus part of one and the same policy initiative, with DMI providing quantitative elaboration of the LAP objectives for a number of specific industries. What we have here, on the one hand, are agreements on maximum growth rates (relative decoupling) for relevant process-related waste streams and, on the other, percentage targets for landfill, incineration and recycling/useful application. These have already been discussed in section 5.3.1.

→ Main effects: dematerialisation, recycling (incl. in other supply chains)

Long-Term Agreements on Energy efficiency

Dutch industry policy is currently geared mainly towards climate change. In the realm of energy efficiency there are two negotiated agreements on energy efficiency at present: the 2nd Long-Term Energy Efficiency Programme (MJA-II) and the Benchmarking Covenant for big energy consumers. In addition, an emissions trading scheme is to be started in 2005, with an absolute collective ceiling for the industries involved (some of which also participate in the covenants).

The Benchmarking Covenant and emissions trading have no direct impact on materials consumption. Efficient materials use is explicitly cited as one of the aims of MJA-II, however, to be addressed via the amount of energy embodied in materials. Among other things, the policy directly addresses weight and composition. The effects on materials consumption are thus both direct and intentional, even though the Covenant is in fact geared to reducing cradle-to-grave energy consumption rather than the weight of the materials used.

→ Main effects: substitution, dematerialisation, recycling

Substance-specific policy

The Strategy on Substance Management (SOMS) is broad in scope, addressing environmental issues, workplace conditions and consumer protection. The overarching aim is to ensure safe use of hazardous substances throughout their entire life cycle. The main focus is on data gathering and dissemination, categorisation of the substances in use in the Netherlands and the precautionary principle. As with the allied European programme REACH (Registration, Evaluation and Authorisation of Chemicals[30]), this policy is still being elaborated and in Europe there are heated discussions on REACH. One of the obligations for industry under REACH is registration and categorisation of all substances imported or produced in quantities of more than one tonne per annum. The focus is thus not on emissions of (toxic) substances, which are covered by the EPER emissions register, but on the *use* of such substances in products and supply chains.

[30] In the definitions section it is stated that ‘chemicals’ is a ’general term to cover both substances and preparations’, with other sections of the document making it clear that ‘substances’ is also to be taken to include metals, etc.

This 'substance policy', if indeed implemented, will probably reduce the magnitude of many toxic substance flows. Of the materials selected for consideration in the present project, heavy metals may possibly be affected.

→ Possible effect: dematerialisation, substitution (in the future)

5.4 Product policy

Product policy is concerned with a later phase of the supply chain: the end product, addressing such issues as energy efficiency during use of consumer products, more sustainable design of such products and 'take-back' obligations for manufacturers.

Two types of product policy can be distinguished: specific policy, geared to a single product or product group, and Integrated Product Policy (IPP), which is generic.

5.4.1 Generic policy: Integrated Product Policy

General product-oriented policy can be seen as a variety of IPP, the aim of which is to reduce the cradle-to-grave environmental impact of (end) products by setting standards for those products. The reasoning here is that it is the end product that drives the overall supply chain and therefore provides good policy leverage. Although IPP as such has not been formalised as a policy in the Netherlands or the EU, European Communication COM(2003)302 sets out a strategy that may culminate in new policy in this area. The associated instruments are Design for the Environment, certification and labelling schemes and product panels.

PMZ

The Netherlands also has an IPP-like programme of 'product-based environmental care' known as PMZ, which until 2003 was subsidised by the environment ministry VROM. Under these subsidised projects, information systems were set up to chart the details of individual supply chains. In most cases, though, actual product modifications to reduce cradle-to-grave environmental burden will only be feasible in the longer term.

→ Possible effect: not yet significant

Environmental certification (product level)

In terms of raw materials and energy requirements, waste generation, pesticide use and scope for recycling, products certified under the *Milieukeur* environmental certification scheme are considerably more benign than conventional alternatives. The scheme, with a precise set of criteria for each product category, encourages recycling (of concrete ware, for example) as well as substitution geared to reducing environmental impact (e.g. for furniture: EKO-certified textiles (profile substitution) and no lead (materials substitution)). Although dematerialisation is not explicitly mentioned as a certification criterion, in some cases minimum requirements are set with respect to product service life.

This does achieve some degree of dematerialisation, as a longer service life[31] implies enhanced functionality. For several product groups there are also criteria for reparability and ease of disassembly.

At the moment the main focus of *Milieukeur* is on agricultural and livestock supply chains. The market share of these products is also very small, as reported in the 2003 annual report of the organisation running the scheme. Its very continuation is in fact uncertain, as the ministry of agriculture is to withdraw its subsidy. In the context of the present review, the overall impact of this certification scheme appears to be negligible.

The European 'Ecolabel' certificate has similar criteria. Minimum requirements on service life, ease of disassembly and use of plastics appear to be the main elements impacting on dematerialisation and recycling and perhaps to some degree on (profile) substitution.

→ Main effect (minor): substitution, dematerialisation, recycling

Energy label

The Netherlands only has an energy label for household appliances (under regulations implementing European directive 92/75/EEG). It distinguishes several levels of energy efficiency and is thus quantitative and is obligatory for certain types of product. Where relevant, data on noise levels, water requirements, etc. must also be provided.

For energy-efficient office equipment there is the international 'Energy Star', a voluntary labelling scheme certifying that products consume less than a certain amount of power during use and in stand-by mode.

Energy labelling might impact indirectly on dematerialisation or substitution if the operational energy efficiency of the appliance were increased through materials-saving measures. There are no clear examples of this, however, and we estimate the overall effect to be marginal.

→ Possible effect: not significant

Design for the Environment

Design for the Environment (DE) is an IPP-type policy instrument, as it seeks to promote an approach to product design that minimises a product's cradle-to-grave environmental impact in terms of energy consumption during usage as well as the materials and toxic substances employed in manufacturing it. At the EU level a draft directive on 'Ecological design of energy-consuming products' is currently under discussion that explicitly cites product dematerialisation as one of its aims.

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[31] For the *Milieukeur* as well as Ecolabelling scheme, however, service live criteria are not sufficiently stringent for any great impact to be anticipated (3 years for refrigerators, for example, and 12 years replacement and service after model discontinuation).

Besides this 'Ecodesign' directive, the directive on 'Waste electrical and electronic equipment' (2002/96/EC) is also concerned explicitly with product design, mentioning issues of reparability, ease of disassembly, reuse and recyclability or 'useful application'. This directive is likely to have an impact on the recycling of white and brown goods (and their components) and possibly also on dematerialisation, as designing with disassembly in mind may often lead to more efficient use of materials.

The overall thrust of this directive has already been implemented in the Netherlands in the White and Brown Goods (Disposal) Decree. In August 2004 this
decree was superseded by new regulations formally implementing the European directive, but in practice things will remain largely unchanged.

→ Main effects: recycling, substitution, dematerialisation

5.4.2 Specific product policy

The Netherlands has dedicated policies in place for the following categories of end products:

1 Cars (end-of-life vehicles and tyres).
2 White and brown goods (electrical and electronic appliances).
3 Batteries and accumulators.
4 Light sources (particularly mercury in fluorescent tube lights).
5 Cable waste.

Under the national Waste Management Plan (LAP) a sectoral plan has been elaborated for each of these categories detailing requirements as to waste disposal. For more details the reader is referred to Appendix K.

This dedicated product policy on the waste phase of specific products and product groups consists of take-back obligations for manufacturers or collection targets, in some cases accompanied by recycling targets. In the case of cars and white and brown goods, the consumer pays an additional 'disposal fee' on purchasing the product. The percentage collection rates as well as the recycling rates of the fractions collected are generally high. These percentages are for the total weight of the fraction in question. Some materials in the fraction are not amenable to recycling, however.

→ Main effect: recycling

5.4.3 Unintentional product policy: vehicle circulation tax

In addition to product policy focusing on the waste phase, as described above, purchase taxes and other forms of consumer taxes on specific products may affect materials consumption. In the Netherlands this is the case for vehicle circulation tax (road tax), which is graded according to vehicle weight. By exerting direct policy leverage on product weight, this tax therefore has an (unintended) dematerialisation impact, with a trend towards use of less material per unit product, i.e car. There is also an impact in the form of substitution, though, with a trend towards greater use of aluminium and plastics to reduce vehicle weight. It should be noted, however, that such substitution need not always benefit the environment.

→ Main effect: dematerialisation, substitution

5.5 Raw materials policy

5.5.1 Surface minerals

Raw materials policy addresses the very first link in the supply chain. The reasoning here is that all environmental damage is linked ultimately to natural resource consumption and that this therefore provides another solid leverage point for environmental policy.

In the Netherlands there is scarcely any general materials-related policy at the moment that directly addresses this ‘cradle’ element of the chain. It is only for energy resources, i.e. fossil fuels, that a direct consumption tax is in place. Although a tax on surface minerals was proposed around 2000, it was not implemented. A scheduled Second Structural Plan on Surface Minerals was also abandoned. In the 4th White Paper on Water Management (drawn up under tripartite ministerial responsibilities for Transport, Public Works and Water Management) there is some focus on the impacts of resource extraction in the context of public works. Priority is given to use of secondary materials (recycling) and renewable resources (e.g. wood) Consultations are currently underway between industry and provincial and national government to draw up an Implementation Plan for the quarrying of mason and concrete sand in the Netherlands.
Policies on extraction of surface minerals have been delegated to provincial executives and are geared largely to security of supply. However, in Limburg (the province supplying the bulk of the Netherlands’ surface minerals) there are also plans for a (small) increase in the use of secondary materials, maximum quality of ‘useful application’, use of surface minerals from existing quarries, safety measures and ‘nature development’ at quarrying sites.

→ Possible effects (minor): substitution, dematerialisation and environment

5.5.2 Natural resource certification schemes

One scheme leading to some amount of profile substitution is the FSC certificate for sustainably produced wood, discussed in section 5.2.2. Although wood is not among the materials included in the present review, it is used as a feedstock for paper and board (although according to FSC the share of certified wood in this market is minimal[32]) and as a building material (where there is a small market for certified wood in the DIY and road and waterway engineering sectors).

When the Dutch government first adopted a policy position on tropical timber in 1991 the stated objective was 100% sustainably produced tropical hardwood. By the end of 2003, though, the market share of FSC-certified wood (tropical and temperate hardwoods, with FSC the only major player in this field) was a mere 10%. It is also anything but clear what instruments the government intended to use to achieve the 100% objective. It is worth remarking that the initiative for the FSC certificate was in fact taken by the industry, NGOs (environmental and human rights groups) and local political parties. It should also be noted that the aforementioned *Milieukeur* certificate also has criteria stipulating that wooden products and components (kitchen units and furniture) be made of sustainably produced wood.

Another development to be mentioned under the heading 'profile substitution' is the use of biotic resources for bioplastics production. Under the terms of the 'Transition Management' policy elaborated by the ministry of economic affairs in pursuit of sustainability there is a specific 'Transition Route' for Bioplastics (no. C3, one element of a wider 'Energy Transition'). The envisaged outcome is '*introduction of biomass as a substitute for fossil energy resources and improved energy efficiency through production, marketing, use and recycling of polymers (i.e. plastics) made from biomass*'. Plastics with a service life of less than 2 years could easily be replaced by bioplastics. The main effect of such a step would be a net decrease in greenhouse gas emissions. The target set under the 'Transition Management' strategy is 'to use bioplastics wherever possible in applications with a short service life (< 2 years) *by the year 2040*'. It should be noted that the environmental benefits of bioplastics are still not entirely clear and there is a need for an LCA-type study to clarify the issue.

5.6 Summary of influence of current policy

In the previous three sections we examined the various policies currently in force in the Netherlands that affect materials and material flows. In this section we summarise these policies and estimate their effect on the individual materials selected for review, by assessing the share of the flow affected by relevant policies and the magnitude of the impact in each case.

In most cases, policies affect only a certain part of the overall flow of a given material and to determine what fraction we first need to know the share of various applications (e.g. packaging) in that overall flow (e.g. paper). Appendix L provides the quantitative data used for this purpose with their respective sources.

For each of the policies reviewed in this chapter, most of which are either sector- or product-oriented, the following table lists the main kind of impact, the

[32] *'FSC in de markt: De beschikbaarheid van FSC-gecertificeerd hout op de Nederlandse markt 2000-2003',* November 2002.

estimated magnitude of that impact[33] and the share of the total material flow affected (table 7).

table 7 Impact of current Dutch policies on selected material flows

Policy	Material affected	Main impact	Estimated magnitude	Share of total flow
Product				
Sectoral plan, end-of-life vehicles	aluminium	recycling	large	<10%
	steel	recycling	large	<10%
	zinc	recycling	large	<10%
	plastics, rubber	recycling	large	<10%
	glass	recycling	large	<10%
	lead	recycling	large	10-25%
Sectoral plan, white and brown goods	?	recycling	large	?
Sectoral plan, batteries	lead	recycling	large	> 50%
	zinc	recycling	large	?
	plastics	recycling	large	very small
Sectoral plan, cable waste	copper	recycling	large	25-50%
	lead	recycling	large	< 5%
Vehicle Circulation Tax	aluminium	dematerialisation	small	<10%
	steel	dematerialisation	small	<10%
	zinc	dematerialisation	small	<10%
	plastics, rubber	dematerialisation	small	<10%
	glass	dematerialisation	small	<10%
PMZ	various	?	?	unknown, probably < 10%
Certification schemes	various	dematerialisation	unknown	unknown, probably < 10%
Energy labelling	various	dematerialisation	unknown	unknown, probably < 10%
Design for the Environment	various	dematerialisation, recycling	?	?
Sector				
‘Green Mortgage’ scheme	concrete	substitution	unknown	unknown, probably < 10%
Covenant on public housing projects	?	substitution	small	?
Building Decree	const. materials	recycling		> 50%
Building Materials Decree	const. materials	substitution	large	> 50%
Regulation on non-recyclable and non-incinerable building and demolition waste	const. materials			> 50%

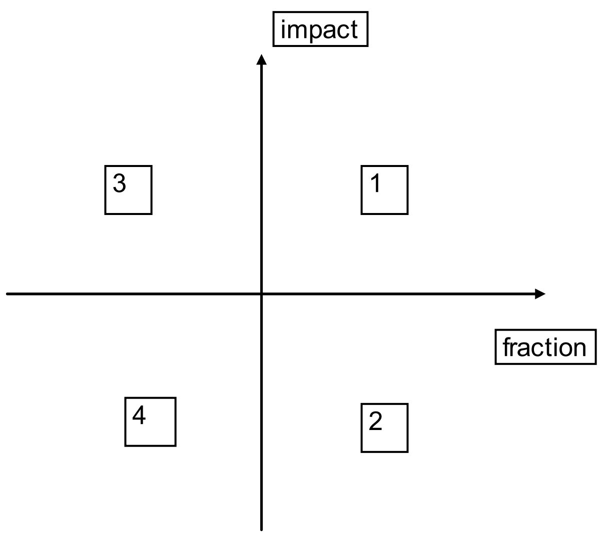
33 It is beyond the scope of this study to evaluate the effectiveness of all these policies in any detail and the assessments given in the table are simply first-pass estimates.

Policy	Material affected	Main impact	Estimated magnitude	Share of total flow
Packaging covenant	steel	recycling	large	?
	aluminium	recycling	large	< 10%
	glass	recycling	large	25-50%
	paper/board	recycling	large	+/- 50%
	plastics	recycling	large	?
Sectoral plan, plastics	plastics	recycling	large	?
Sectoral plan, textiles	animal fibres	recycling	large	?
Sectoral plan, metals waste	steel	recycling	unknown	?
	aluminium	recycling	unknown	?
	zinc	recycling	unknown	?
	lead	recycling	unknown	?
	copper	recycling	unknown	?
Sectoral plan, industrial waste	const. materials	substitution	unknown	?
Sectoral plan, office, shop & service waste	various	various	unknown	?
DMI	(1)	(1)	(1)	(1)
SOMS	all	dematerialisation, substitution	unknown	100%
MJA2	various	substitution, dematerialisation, recycling	unknown	?

1) Arrangements under DMI are as per LAP sectoral plans.

Using the results reported in this table, for each of the selected materials we endeavoured to estimate the approximate overall impact of the various policies reviewed in this chapter. To this end we used a straightforward two-dimensional matrix, as shown in figure 41.

figure 41 Matrix for assessing policy impact: 1 is major impact on large fraction of flow, 4 is minor impact on small fraction of flow, etc.



Using this matrix and the data of table 7, then, table 8 summarises the estimated overall impact of the array of policies on the flow of each material selected for review here. In the case of heavy metals, these estimates are less certain than for other materials.

table 8 Summary overview of impact of current Dutch policies (darkest cells have greatest impact)

	Dematerialisation	Substitution	Recycling
Aluminium	2	2 (neg)	1
Steel	2	2	1
Copper	4	3	3
Lead	4	3	3
Zinc	4	3	3
Nickel	4	3	3
Glass	2	1	1
Plastics, rubber	4	3 (neg)	3
Paper / board	2		1
Ceramics			2
Concrete			1
Sand			2
Cement			2
Animal fibres			1

Note: 'neg' (for 'negative') means that substitution leads to increased consumption of the material in question and that this may have a negative environmental impact.

As can be seen, the bulk of these policies address the recycling of waste flows, with far less focus on the use of more environmentally benign materials and/or dematerialisation. Above all, the current array of policies provides few incentives for dematerialisation. Although there is a little more impact on substitution, this holds for a few materials only.

5.7 Concluding remarks

5.7.1 Chapter synopsis

As the above review shows, current Dutch policy affects material flows mainly by way of recycling. This is not only the most frequent (direct) policy goal; it is also probably where the greatest results are being achieved. In most cases dematerialisation and substitution are merely side-effects, in part unintended.

The main area where there is likely to be some dematerialisation is packaging materials, while substitution will be mainly of steel, in various applications, and glass packaging, because of the high density of these materials. The replacement materials are often aluminium and plastics and substitution will therefore lead to greater consumption of these. Finally, there will probably also be some substitution of heavy metals (for what materials we were unable to determine) because of various standards relating to the use of this kind of toxic material. In the future, substance policies like SOMS and REACH may possibly also have an impact on dematerialisation for heavy metals.

5.7.2 Comparison with fuels and food crops

Although there are no policies directly addressing consumption of the above materials *sensu stricto*, the situation is different for fuels, on which consumers pay excise duty and a Regulatory Energy Charge. There are also more financial policies in place for 'energy chains', as is the case for 'food chains', including the 'Green Projects' programme (*Regeling Groenprojecten*). These are concerned with environmental impact, however, rather than materials weight (use).

The Dutch environmental labels (*Milieukeur*, EKO) mainly address food supply chains. In this context, manure policy can also be deemed a sectoral policy, even though it addresses environmental impact rather than materials consumption.

table 9 Policy coverage of the three main supply chains

	Dematerialisation	Substitution	Recycling	Environmental impact + profile substitution
Energy chains	+	+	n.a.	+
Food chains	n.a.	n.a.	n.a.	+
Material chains	+/-	+/-	+	-

For energy resources, moreover, all effects having a bearing on environmental impact due to 'materials consumption' are covered except for direct recycling, which in the case of energy is inapplicable.

5.7.3 Conclusions

It is clear that by far the majority of the policies discussed in this chapter address the waste phase of the life cycle and are designed to promote recycling and/or re-use. In the Dutch context it is thus waste policy (LAP, 3rd Packaging Covenant) that has the greatest impact on materials consumption. It should be noted, though, that for a number of product groups targets have been set for separate waste collection only, and there need not necessarily be any (additional) recycling of the materials in question. Waste policy is therefore not necessarily material flow policy in the sense of it having any real impact on the materials consumption of the national economy as a whole.

Recycling is probably a cost-effective and efficient mechanism. Substitution, by contrast, does not necessarily lead to environmental gains as things stand at present. Replacing steel by aluminium is controversial in this respect, for example. Policies having an effect on profile substitution (improved environmental profile rather than improved material efficiency) such as environmental certification schemes and certain regulations for the construction industry may be effective, but are very specific in what they steer.

The only policy instruments having any impact on dematerialisation and substitution at the moment seem to be road tax and the 2nd Long-Term Energy Efficiency Programme (MJA-II). It should be noted, though, that the dematerialisation impact of MJA-II will probably remain fairly insubstantial for the time being. Interestingly, road tax and MJA-II aim to reduce road surface wear and energy consumption, respectively, rather than materials consumption as such. What we see here, then, are largely unintended side-effects.

There is some policy aimed at rendering material flows sustainable[34], termed 'profile substitution' in this study. Thus, at the materials level, efforts are being made to make Dutch wood consumption sustainable and promote the use of biomass feedstocks by the chemical industry. At the product level, there are environmental certificates and other labelling schemes. The main impact of these is in terms of sustainability (i.e. environmental gains), with only very little effect on dematerialisation or substitution. The *Milieukeur* eco-labelling scheme does not in fact even have any explicit criteria for the recyclability of actual products, only for that of the packaging, except in the case of a handful of products that are themselves to be made of secondary materials.

[34] This policy area is beyond the scope of the present review.

6 Conclusions

6.1 Main conclusions

There is growing international interest in establishing some form of economy-wide material flow policy, i.e. policy addressing the overall throughput of materials in national economies. In the Netherlands, too, the 4th National Environmental Policy Plan (NEPP4) has stated the government's intention to introduce a policy on natural resource use.

This kind of policy may indeed serve a useful purpose, as all the materials flowing into the economy sooner or later leave it as waste or emissions. In addition, there is a broad consensus that economic activity in the developed North impacts in numerous ways on the environment of the countries in the South. An economy-wide material flow policy could help reduce this 'overseas' impact.

The overall objective of an economy-wide material flow policy can be stated as follows:

The aim of an economy-wide material flow policy is to reduce the cradle-to-grave environmental impact of natural resource use (in relative or absolute terms), irrespective of where that impact occurs, through changes in the scale and nature of the resources and materials consumed.

A key point here is that a material flow policy should encompass more than merely dematerialisation (improved material productivity and/or a decline in material inputs). Just as important are the opportunities for substituting environmentally more benign materials and using recycled materials if that indeed yields environmental gains. The above definition also establishes a dividing line between this kind of policy and existing emissions policies such as IPPC: the emissions occurring during materials production are *not* addressed by material flow policy. With policy scope thus delineated, a material flow policy can be designed that supplements existing environmental policy rather than cross-track it.

The indicator used to monitor an economy-wide material flow policy must be in line with the defined policy goal. This is not the case with DMC (Direct Material Consumption), which simply aggregates material flows on the basis of weight. It is only in the short term that a decline in DMC will correlate with a decline in environmental burden as a result of dematerialisation. In particular, this indicator does not capture the environmental effects of materials substitution.

In this study we endeavoured to combine information on tonnage material flows with LCAs, an approach that yielded promising results. An indicator has been constructed: EMC (Environmentally-weighted Material Consumption) that can monitor trends in the cradle-to-grave environmental impact associated with the economic consumption of materials. The fact that this indicator is based on a material's environmental impact rather than sheer weight we see as a major improvement on the indicators proposed to date in the international literature.

With the EMC presented here, the main policy leverage to be exerted is on dematerialisation and materials substitution, including use of recycled materials if that is environmentally beneficial. Our indicator successfully measures changes in precisely these areas and can in fact be used at company-level to assess whether use of a particular substitute material will indeed reduce corporate environmental impact.

The EMC developed here does not measure the actual environmental burden of present-day materials consumption, for that consumption has been weighted according to the impact categories from an LCA database. This means that implementation of more benign processes at materials-consuming industries is not immediately reflected in the indicator, but only after a lapse, when the LCA database is updated. Past experience shows that updates are to be expected every five to ten years. The materials-related environmental impact can then be adjusted to accommodate the state of the art and recalculated. In this sense the indicator is akin to the inflation index used by Statistical Offices, which is also periodically adjusted to reflect changes in household spending on the 'basket of goods'. This need not detract from the usefulness of the indicator for policy purposes, however, because it is dematerialisation and materials substitution that such policy is principally addressing, rather than a reduction of the environmental impact of materials-producing industries via end-of-the-pipe or process-integrated measures, which are already sufficiently well covered by standing environmental policies.

The policy analysis undertaken in this study shows that there are currently few policies geared to dematerialisation or use of more environmentally benign materials. Much of the policy with a materials component is in fact waste policy, geared to reducing the environmental impact of final waste disposal through greater use of recycled materials. As a result, key opportunities further up the supply chain remain unexploited. The 'umbrella' of an economy-wide material flow policy could increase the coherence of existing policies and provide an integrated framework for policy analyses. It would also allow options for dematerialisation and use of more benign materials (measured from cradle to grave) to be better utilised and promoted. The EMC indicator would thus appear to be an important addition to standing materials-related policies.

6.1.1 Recommendations and conclusions on methodological and data aspects of indicator construction

The main conclusion is that combining LCAs with material flow analysis is a feasible procedure yielding useful results. Importantly, the Environmentally-weighted Material Consumption (EMC) developed here is more in line with the policy goal of an economy-wide material flow policy. One drawback is that the system boundaries are not pre-determined and that to arrive at a uniform indicator the various environmental impact themes must be appropriately weighted relative to one another.

The EMC indicator also has a number of statistical limitations and with respect to these we make the following recommendations:

- The reliability of the environmental indices reported here depends above all on the quality of the LCA database employed. The database used in this project is constructed around the environmental impact data available in 1996 and works with European averages. These averages may not always be representative of Dutch products made of the same materials and the results for certain (groups of) materials may therefore be somewhat distorted. On the one hand, this implies a need to update the database every few years to be sure the raw data remain representative of the calculated environmental impacts of the materials. On the other hand, it argues for creating country-specific LCA databases that make distinctions as to country of origin. This is readily feasible, at some point in the future, if it goes hand in hand with a monitoring system for labelling materials with an environmental rating.
- For the usage and waste phases of the life cycle, we appended several assumptions of our own to the database. For satisfactory results, this will have to be standardised. An update of the database used in this study was recently released and it is recommended that this be used in the future.
- The current LCA database does not distinguish sufficiently between primary and secondary materials. This needs to be further refined in the future.
- There are specific problems regarding assessment of the environmental impact of plastics. Although these impacts are registered fairly precisely in the LCA database, down to the level of individual plastics (PE, PVC, PP, PS, PC), they cannot be properly applied because no exact data are available on real-world production and consumption of these individual plastics, or even of plastics as a whole. If a material flow policy is indeed implemented, it is recommended to improve the monitoring of plastics flows. As issues of confidentiality are often at stake here, means should be found to monitor consumption of these materials without enabling the output of individual companies to be derived.
- Volume data were taken from standard statistical sources and the contradictions sometimes encountered led at times to curious results. Trade statistics, in particular, appear to be fairly unreliable. This is very worrying. If the indicator is to be used to monitor trends, it is recommended to charge Netherlands Statistics (CBS) with compiling volume data.
- To a greater or lesser extent, every indicator is sensitive to the structure of the economy it is being used to monitor. Exporting nations have a higher DMI, mining nations have a higher DMC, while the EMC developed here is higher for nations with a large manufacturing base. These influences should be borne in mind when indicators are used to make inter-country comparisons.

6.1.2 Recommendations and conclusions on policy issues

A material flow policy making use of the EMC developed here can serve to effectively supplement standing policy. It can also be used to back up existing Integrated Product Policy and waste policy. Our indicator ties in well with IPP; the method is in fact completely synonymous with IPP, apart from the environmental impact associated with actual usage of a product not being attributed to a particular material or materials. For example, the score of aluminium does not embody any benefits accruing from using aluminium to replace (heavier) steel in vehicle manufacture. In the scheme developed here, however, these benefits come under the heading of energy policy. We therefore recommend that the environmental impact of product usage, which is not specifically associated with the materials from which the product is made (as in the case of energy consumption), remain outside the scope of the indicator.

This indicator can also be used to assess whether certain materials may be contributing disproportionately to all environmental problem themes. A material flow policy addressing these materials would yield the greatest environmental gains and certainly be more focused than an across-the-board policy geared simply to total material tonnage. Cradle-to-grave LCAs on specific materials may be useful for localising where precisely in the supply chain the environmental impacts are occurring and suggesting options for improving the overall environmental profile of the material in question. This information may also be useful to industries seeking to enhance the profile of the specific materials they produce.

How exactly a policy geared to the environmental impact of materials consumption can best be implemented is an issue requiring separate discussion. It is not something we have endeavoured to address here. It is a misunderstanding, however, to think that material flow policy is exclusively a government affair. In the initial phase, it could well be an option to link up with ‘corporate responsibility’ initiatives. In this scenario the role of government would be mainly supportive, providing a standard methodology, for example. The indicator developed here would then first have to be tested by a panel of potential users, to our mind specifically from the construction and manufacturing industries. Another option would be to tie an economy-wide materials flow policy into the 2nd Long-Term Energy Efficiency Programme (MJA-II), giving resource-consuming industries the additional option of securing their energy conservation targets by means of life cycle materials policy, and vice versa. These and other options will need to be duly examined if and when it is decided to move ahead on elaboration of an economy-wide material flow policy.

The question of whether that is necessary is a pertinent one. As this study has shown, there a number of opportunities for reducing the environmental impact of production and consumption that are not currently being utilised by environmental policy-makers.

Literature

Adriaanse A., S. Bringezu, A. Hammond, Y. Moriguchi, E. Rodenburg, D. Rogich and H. Schütz
Resource Flows: The Material Basis of Industrial Economies.
WRI, Washington D.C., 1997

Ayres, R.U., A.V. Kneese
Production, Consumption and Externalities. American Economic Review, 59: 282-297, 1969

Ayres, R.U., F.B. Schmidt-Bleek, 1993
Towards a universal measure of environmental disturbance. Centre for the Management of Environmental Resources
INSEAD Working paper no. 93/36/EPS, Fontainebleau, France, 1993

Daly, H.E.
Steady State Economics: Second Edition with New Essays
Island Press, Washington DC, 1991

Davidson, M., A .Hof, and B. Potjer
Update Schaduwprijzen: financiële waardering van milieuemissies op basis van Nederlandse overheidsdoelen
CE-Delft, The Netherlands, 2002

Bruyn, S.M. de
Economic growth and the Environment: An empirical analysis
Kluwer Academic Publishers, Dordrecht, The Netherlands, 2000

Bruyn, S.M. de, J.B. Opschoor
Developments in the throughput-income relationship: theoretical and empirical observations
Ecological Economics **20**: 255-268, 1997

Bruyn, S.M. de, J. Vroonhof, B. Potjer, A. Schwencke, J.P. van Soest
Minder meten, meer weten!: De toepassing van indicatoren voor dematerialisatiebeleid
CE-Delft/Netherlands 03.7159.03 Environment ministry (VROM), 2003

Bruyn, S.M. de, E. van der Voet, A.M. Idenburg. J.C.J.M. van den Bergh, H. Verbruggen
Minder materialen, beter milieu
Economisch Statistische Berichten (ESB), no. 4431, 2004

EC (European Commission)
Towards a Thematic Strategy on the Sustainable Use of Natural Resources
COM(2003) 572 final, 2003

EUROSTAT
Economy-wide material flow accounts and derived indicators: A methodological guide
Office for Official Publications of the European Union, Luxembourg, 2001

EUROSTAT
Material use in the European Union 1980-2000: Indicators and analysis
EUROSTAT Working Paper and Studies, Luxemburg, 2002

EZ
Derde Energienota
Netherlands Ministry of Economic Affairs, Sdu Publishers, The Hague, 1996

Frischknecht, R.
Ökoinventare für Energiesysteme
Parts 1-3 and dataset, Institut für Energietechnik ETH, Zürich, 1996

Guinée *et al*.
Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards
Kluwer Academic Publishers. Dordrecht, The Netherlands, 2002 (see also http://www.kap.nl/prod/b/1-4020-0228-9)

Heijungs, R.
CMLCA, Chain Management by Life Cycle Assessment. A software tool to support the technical steps of the life cycle assessment procedure (LCA)
(Software tool with demo files and manual downloadable at http://www.leidenuniv.nl/cml/ssp/software/cmlca/index.html#download), 2003

Heijungs, R., J.B. Guinée, G. Huppes, R.M. Lankreier, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin, and H.P. de Goede
Environmental Life Cycle Assessments of products
Guide and Backgrounds, CML, Leiden University, Leiden, The Netherlands, 1992

Hinterberger, F., S. Giljum, M. Hammer
Material Flow Accounting and Analysis (MFA): A valuable tool for Analyses of Society-Nature Interrelationships
Background Paper series no. 2, 2003

Hoekstra, R.
Structural change of the physical economy: Decomposition analysis of physical and hybrid-unit input-output tables
PhD thesis, Free University, Amsterdam. Tinbergen Institute Research Series no. 315. Thela Thesis Academic Publishing Services, Amsterdam, 2003

Malenbaum, W.
World Demand for Raw Materials in 1985 and 2000
McGraw-Hill, New York, 1978

Matthews, E., C. Amann, S. Bringezu, M. Fischer-Kowalski, W. Hüttler, R. Kleijn, Y. Moriguchi, C. Ottke, E. Rodenburg, D. Rogich, H. Schandl, H. Schütz, E. van der Voet and H. Weisz
The Weight of Nations: material outflows from industrial economies
World Resource Institute, Washington DC, 2002

OECD (Organisation for Economic Co-operation and Development)
OECD Core Set of Indicators for Environmental Performance Reviews: A synthesis report by the Group on the State of the Environment
Environment Monographs, no. 83, OECD, Paris, 1993

OECD
Recommendation of the council on material flows and resource productivity
Endorsed by Environment Ministers on 20 April 2004, adopted by the OECD Council on 21 April 2004, Paris

Reijnders, L.
The Factor X Debate: Setting Targets for Eco-efficiency
Journal of Industrial Ecology **2**: 13-22, 1998

RIVM
Milieubalans 2003; Het Nederlandse milieu verklaard
Kluwer, Alphen aan de Rijn, The Netherlands, 2003

Schmidt-Bleek, F.
Wieviel Umwelt braucht der Mensch - MIPS, das Mass für oekologisches Wirtschaften
Birkhaeuser, Basel, Boston, Berlin, 1993

Stern, D.I., M.S. Common and E.B. Barbier
Economic Growth and Environmental Degradation: A Critique of the Environmental Kuznets Curve
World Development, 24: 1151-1160, 1996

Tilton, J.E.
The OECD Countries: Demand Trend Setters. In: J.E. Tilton (ed.), World Metal Demand: Trends and prospects
Resources for the Future, Washington DC, pp. 35-76, 1990

United Nations
System of Environmental and Economic Accounting
SEEA 2000 Revision. United Nations, New York, 2001

Van den Bergh, J.C.J.M., H. Verbruggen and M. Janssen
Belastend materiaal. ESB
1 November 2002: 783-785

Van der Steenhoven, Augustijn-Esser *et al.*
Parliamentary Motion, year 1999-2000
17 November 1999, KST41929, Sdu Publishers, The Hague, The Netherlands

Van der Voet, E., van Oers, L. and I. Nicolic
Dematerialisation: not just a matter of weight
CML report 160, Leiden, The Netherlands, 2003

Von Weiszäcker, E., A.B. Lovins and L.H. Lovins
Factor Four, doubling wealth, halving resource use
The new report to the Club of Rome, Earthscan Publications, London, 1997

Wackernagel, M. and W.E. Rees
Our ecological footprint: reducing human impact on the earth
New Society Publishers, Gabriola Island, 1996

Williams, R.H., E.D. Larson and M.H. Ross
Materials, Affluence and Industrial Energy Use
Annual Review Energy, 12: 99-144, 1987

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Material flows through the economy and environmental policy

An analysis of indicators and policy applications for economy-wide material flow policy

Appendices

Report

Delft, December 2004

Commissioned by the Netherlands Ministry of Housing, Spatial Planning and the Environment, H. (Henk) Strietman

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A OECD Council Recommendations

Endorsed by Environment Ministers on 20 April 2004
Adopted by the OECD Council on 21 April 2004;

THE COUNCIL,
Having regard to Article 5 b) of the Convention on the Organisation for Economic Co-operation and Development of 14th December 1960;

Having regard to the Recommendation of the Council of 8th May 1979 on Reporting on the State of the Environment [C(79)114)];

Having regard to the Recommendation of the Council of 31st January 1991 on Environmental Indicators and Information [C(90)165/FINAL];

Having regard to the Recommendation of the Council of 20th February 1996 on Implementing Pollutant Release and Transfer Registers [C(96)41/FINAL] amended on 28th May 2003 [C(2003)87];

Having regard to the Recommendation of the Council of 3rd Asspril 1998 on Environmental Information [C(98)67/FINAL];

Having regard to the Communiqué of the OECD Council meeting at Ministerial level of 17th May 2001 which stated that 'that OECD countries bear a special responsibility for leadership on sustainable development worldwide, historically and because of the weight they continue to have in the global economy and environment' and which asked the OECD to 'continue to assist governments by: developing agreed indicators that measure progress across all three dimensions of sustainable development, including decoupling of economic growth from environmental degradation';

Having regard to the OECD's Environmental Strategy for the First Decade of the 21st Century endorsed by MCM in May 2001;

Having taken note of international work on Integrated Environmental and Economic Accounting (commonly referred to as SEEA);

Considering the need for better information designed to integrate more fully environmental and economic decision-making;

Convinced of the need for intensified efforts by OECD member countries to establish and use indicators of progress concerning the implementation of national and subnational policies on the environment, eco-efficiency and sustainable development; and to systematically compare achieved results with relevant objectives of environmental policies and, where appropriate, related international commitments;

Taking into account the close co-operation on environmental matters between OECD and other international organisations;

On the proposal of the Environment Policy Committee (EPOC):

I. Recommends that member countries:
(i) take steps to improve information on material flows, including its quality and relevance for environmental management, in particular:
develop methodologies to enhance knowledge of material flows within and among countries;
consolidate and improve data collection concerning material flows within and among countries;
develop tools to measure resource productivity and economy-wide material flows, including appropriate estimation methods, accounts and indicators;
(ii) further develop and use indicators to better integrate environmental and economic decision-making, and to measure environmental performance with respect to the sustainability of material resource use;
(iii) promote the development and use of material flow analysis and derived indicators at macro and micro levels;
(iv) link environmental and economic related information through work on material flows, stocks and flows of natural resources, environmental expenditure, and macro-economic aspects of environmental policies;
(v) co-operate to develop common methodologies and measurement systems of material flows, with emphasis on areas in which comparable and practicable indicators can be defined, drawing on work already done at national and at international level.

II. Instructs the Environmental Policy Committee:
(i) to support and facilitate member countries' efforts to improve information on material flows and related indicators, including through exchange of information on national and international innovative experiences;
(ii) to continue efforts to improve methods and indicators for the assessment of the efficiency of material resource use in important areas;
(iii) to develop a guidance document to assist member countries in implementing and using common material flow accounts;
(iv) to carry out these tasks in co-operation with other appropriate OECD bodies and other international organisations to prevent duplication and reduce costs;
(v) to report to the Council on progress achieved by Member countries in implementing this Recommendation, within three years of its adoption.

B Summary of the Resources Strategy (EC)

Brussels, 1.10.2003
COM(2003) 572 final - Executive Summary

This Communication is a first step towards the Thematic Strategy on the Sustainable Use of Natural Resources (Resources Strategy), called for in the EU's Sixth Environment Action Programme. It aims to launch a debate on a framework for using resources which supports the objectives of the Lisbon strategy and the EU's sustainable development strategy. After analyzing the environmental issues associated with the use of natural resources, it outlines the main features that a future strategy should comprise, building on existing policies. Although it sets out basic ideas on how the EU should target its efforts to reduce the environmental impacts of resource use, it does not actually propose specific measures to this end. This will be done in the final strategy to be presented in 2004.

Natural resources provide the basis for the three pillars of sustainable development, economic, social and environmental. However, physical reserves can become depleted and scarce, and this can then undermine future economic and social development. Moreover, the way in which resources are used can reduce the quality of the environment to an extent that can threaten ecosystems and the quality of human life. At present the environmental impacts of using non-renewable resources like metals, minerals and fossil fuels are of greater concern than their possible scarcity. With fossil fuels for example, it is the greenhouse gases from their use that are a pressing problem today rather than the risk of reserves running out. With renewable resources like fish, clean water and land the picture is different because of loss of biodiversity and habitats. The Resources Strategy should therefore focus on reducing environmental impacts, thus enabling growing economies to use resources efficiently, from both an economic and an environmental point of view. This de-linking - commonly called decoupling - of impacts from growth is the overarching goal to which this strategy will contribute. It will be necessary to ensure that policies that influence directly or indirectly the use of resources strike a balance between the economic, environmental and social pillars of sustainable development.

Implementing new policies and adapting existing ones in order to achieve the necessary decoupling of resource-related environmental impacts from economic growth will be a long-term process. Businesses, consumers and institutions need time to develop and adopt production and consumption patterns with lower impacts. They will also need public policies with clear long-term objectives in order to plan investment and innovate. For this reason the time scale for the strategy is 25 years.

The relations between resource use and environmental impact are only partially known at present. Furthermore they change with time, for example, as a result of technical or social developments. Differences in regional conditions and use patterns need also to be considered. In addition, environmental impacts related to the use of different resources vary widely. So, initially the strategy has to determine which resources at any given time are of biggest concern, e.g. the resources with the greatest potential for environmental improvement, taking into account technological possibilities and socio-economic aspects. To perform the functions described above, and to take account of continuously evolving patterns of environmental impacts of resource use, the strategy will comprise three strategic elements that will apply continuously throughout its life.

Knowledge gathering
The entire life-cycle of resources, from their extraction, through their use in the production of goods and services and the subsequent use phase, to the waste phase, gives rise to environmental impacts. Any given raw material can take numerous different pathways through the economy. Aluminium, for example, can be transformed into goods as diverse as window-frames, aircraft bodies and beverage cans, and these all interact in very different ways with the environment. Knowledge about these pathways and impacts is presently dispersed between many actors, and significant gaps exist. The Resources Strategy has to ensure that knowledge is readily available to decision-makers and that gaps are being filled.

Policy assessment
The use of natural resources is influenced by numerous environmental policies, including for example strategies on the marine environment, soil protection, biodiversity and the urban environment, as well as climate change policy, the water framework directive and many others.
In addition, many non-environmental policies strongly influence resource use - sometimes unintentionally. Examples include fiscal, transport, agricultural and energy policies. However, there is currently no mechanism for assessing how far policy-choices in these different areas are compatible with the overall aim of decoupling economic growth from the impacts of resource use. The Resources Strategy will make these assessments, raise awareness of potential tradeoffs, and suggest alternatives wherever possible.

Policy integration
To bring the strategy to life, concrete actions will need to be taken on the basis of the information generated by the previous two strategic elements. This will involve political judgments on the relative importance of different impacts and environmental targets, taking into account wider sustainable development considerations and identifying measures with the greatest potential for environmental improvement of resource use. The Resources Strategy will therefore work towards increasing the integration of resource-related environmental issues into other policies that influence the environmental impacts of the use of natural resources, in particular under the Cardiff Process.
Following publication of this document, the Commission will, in an open and collaborative process involving the Community institutions and stakeholders, develop a comprehensive strategy to be proposed in 2004.

C Dematerialisation and natural resources in NEPP4

In the Netherlands, dematerialisation policy was first introduced under the terms of the 4th National Environmental Policy Plan (NEPP4). Cognisant of the fact that pursuit of 'dematerialisation' has ramifications for a multitude of environmental impacts, the document states (p. 126) that: 'current instruments to reduce these environmental impacts are often more effective as well as cost-efficient. Source-based measures within production processes, for example, will generally spur far greater reductions than dematerialisation. [….] Dematerialisation serves mainly to supplement existing policies, which already provide ample incentives for reducing material inputs as well as energy consumption. Above all, then, dematerialisation policy will lead to elaboration and application of additional policies in the field of materials and energy'.

When it comes to the practical implementation of dematerialisation policy, NEPP4 (p. 143 *et seq.*) sees producers and consumers playing a leading role. 'Among the policies at the government's disposal, dematerialisation will feature more prominently, with modules being developed with the specific aim of reducing materials consumption. Life cycle analysis (LCA) will also have a role to play in this context […]. It must also be clear what environmental benefits are to derive from dematerialisation. This is important not only for trade and industry but for consumers too, for only then will companies and private citizens be motivated to pull their weight. Steps must therefore also be taken to ensure the retail trade has better access to the relevant information, as an added stimulus to improve the sustainability of their product range'.

According to NEPP4 (p. 142) dematerialisation policy must be grounded in a monitoring system, yet to be developed, that '…is focused on resource depletion and energy consumption, and more specifically:

- Monitors trends in materials consumption, in ecosystems and in the economy that herald the move to a sustainable pattern of consumption.
- Analyses the factors governing demand for materials and energy.
- Quantifies the environmental impacts of material flows and energy consumption and, in doing so, any environmental gains accruing (impact on CO_2 emissions is particularly important in this respect).

Overall efforts in these fields will be monitored using a dematerialisation indicator that measures the progress being made on dematerialisation, within individual companies and economic sectors, as well as nationally. 'A dematerialisation indicator shall be developed, based on specific indicators for fossil fuels, wood, food, water, plastics, building materials and metals. Derived indicators for discarded waste may also have a part to play. In developing a dematerialisation indicator, the Netherlands shall mirror European development of such an instrument as closely as possible.'

The ultimate aim of dematerialisation policy is to (help) reduce the environmental impact of material flows. According to NEPP4, this policy will serve above all to supplement climate policy, product policy, waste policy and policies on resource depletion ('efficiency policy'). The policy paper also set an long-term indicative target for dematerialisation, which still holds: by 2030, a 50 to 75% reduction in materials consumption relative to GNP growth - in other words, Factor 2 to 4 dematerialisation [Von Weiszäcker *et al*., 1997].

As part of an earlier study by CE [De Bruyn *et al*., 2003] a series of consultations was held with scientists and policymakers. One of the outcomes was a proposal to exclude fossil fuels from dematerialisation policy, it being felt there are already so many policies relating to energy that there is little point in barging in with new dematerialisation policy. It was also agreed to use the term 'material flow policy' rather than 'dematerialisation policy', as the aim of such policy is not necessarily to reduce the tonnage of materials consumed, substitution and recycling also having a potentially significant role to play in reducing the overall environmental impact of materials consumption.

D Definition of a material and decisions on data collection

Definition of a material

One of the problems addressed in the report 'Dematerialisation: not just a matter of weight' [Van der Voet *et al.,* 2003] is that materials may be categorised at widely differing levels of detail. Thus, the LCA database distinguishes six different types of steel, while breaking the whole of agricultural production down into no more than two materials: plant and animal biomass. Aggregating six types of steel to one is always feasible, if so desired, while subdividing a massively aggregated category is far more difficult, because additional information is required.

Agricultural products prove to be major contributors to the scores of just about every environmental problem. This is due both to the high impacts per kilogram of material consumed (impact/kg) and to high volume consumption in the Netherlands (kg). The high level of aggregation is, of course, one of the reasons for the high score of agriculture almost across the board, making a more detailed breakdown extremely desirable. This opening section is therefore concerned with further subdivision of agricultural biomass.

A key criterion in such classification is the potential for substitution. Are the materials within a given group sufficiently interchangeable to be considered a more or less homogenous group?

One possibility is a breakdown into individual crops, every crop being in theory unique, with full substitution never entirely possible. Although this is indeed feasible, the ensuing list would be excessively detailed. The crop lists to be found in agricultural statistics are extremely lengthy and do not tie in well with the notion of 'materials'. We therefore propose a breakdown of agricultural products into product groups based on (coarse categories of) types of application. Within each group there will be some scope for functional substitution, but it will not be limitless.

We can distinguish three basic applications, or principal functions, of agricultural products:

- Foodstuffs.
- Textile feedstocks (plant: cotton; animal: wool, leather).
- Biotechnology feedstocks: bioplastics, biofuels and fine chemicals.

Although this last category is still relatively modest in scale, it may well grow in the coming years. (This issue is discussed at greater length in Appendix E.)

Agricultural products used as foodstuffs can be broken down into product groups based on the four elements of dietary intake usually identified in recommendations, *viz.*: carbohydrates, fibres, proteins and fats (table 10). This categorisation is useful from the angle of potential for substitution.

table 10 Categorisation of agricultural products according to main constituent

Product group	Dietary function
Potatoes, cereals and pulses	**starch (carbohydrates)**, fibres (cellulose etc.), plant proteins, vitamin B, minerals
Fruit and vegetables	**fibres** and vitamin C
Meat, fish, poultry, eggs and dairy products	**animal proteins,** vitamin B, minerals
Margarine and butter	**fats**, linolic acid, vitamins A and D

Based on this basic fourfold scheme, Table 11 presents a proposal for categorising agricultural products, food and non-food. As it would require a disproportionate effort to work out multiple allocations for each crop (cereals providing starch as well as fibre and a certain amount of protein, for example), we have chosen to allocate crops on the basis of their *principal* function, even though this sometimes means a degree of arbitrariness in the categorisation. The purpose for which the crops are used then represents a new level of detail in the supply chain. In the case of biomaterials these are essentially themselves the 'finished material'. The fraction of crops used as raw materials in biotechnological industries was therefore not included in our quantification of flows. As yet this is only a minor quantity, but this may well change in the future.

table 11 Agricultural product groups and their associated functions (uses)

Product group or material	Application		
	food stuff	textiles	bio-materials
Starch crops for consumption (potatoes, cereals, etc.)	x		
Starch crops as raw materials (cereals, maize)			x[2]
Cellulose crops for consumption (fruit and vegetables)	x		
Cellulose crops as raw materials (cotton, hemp)		x	
Animal fibre products as raw materials (wool, leather)		x	
Protein crops (pulses)	x		
Protein products from livestock farming (meat, eggs)	x		
Protein products from fisheries (fish, crustaceans)	x		
Oil crops (oilseed rape, sunflowers)	x		
Animal fats (dairy products) [1]	x		

1) Margarine and butter are both included with dairy products. Unpasteurised milk is the raw material for consumer milk, cheese, butter and other dairy products.

2) Bio-based plastics and fuels are currently produced mainly from sugars from maize and cereals. Issues of economic viability mean there will be an inevitable shift towards cheaper sugars from sugarbeet, straw, maize residues and so on.

Data collection

Data sources

There are two basic sources of data on material flows. The first are MFA databases, such as those set up by the Wuppertal Institute or by IFF for Eurostat, which contain data at the raw materials level. The second source are production and trade statistics, providing data at the level of finished material or product. The advantage of an MFA database is that it furnishes a complete review in principle, which is not the case with production statistics. On the other hand, the MFA databases provide no information on further articulation of the supply chain. In what materials are the basic resources used and in what finished products do they end up?

There is one source of data on how raw materials ramify into the various downstream applications: the United States Geological Survey (USGS), with data for the United States. In Europe and the Netherlands no such data are available, although the UK is currently setting up a similar database. Provisional results indicate that the distribution of raw materials over downstream applications is not that dissimilar from the US situation (pers. comm., Rebecca White, British Geological Survey). In this study we used the USGS data to fill in data gaps.

For some basic materials this is sufficient, because they are used unprocessed. When we are dealing with materials derived from these basic materials, however, total mass flow data must be sought elsewhere. This is where a third source of data comes in: the EcoInvent LCA database. Although this has no volume data on individual raw materials, it does have data on the composition of the materials and products made from them. Using this information, then, we could make reasoned estimates for any data gaps still remaining.

Use of data sources
The first choice was to consult the production and trade statistics to ascertain the volume of the material in question. If the material is listed, [laatste zo goed?] there is no problem. These data are often lacking, however, and total volume consumption must then be estimated. The method used is explained below with reference to an example.

Assume the MFA database has data on the flows of raw materials X, Y and Z, say, while the USGS database has data on the distribution of raw materials X and Y over finished materials A, B and C:

Raw material X [tonne/y]
- 20% goes to application A
- 30% goes to application B
- 50% goes to application C

Raw material Y [tonne/y]
- 10% goes to application A
- 90% goes to application B

Raw material Z [tonne/y]
- unknown

The LCA database has data on the composition of finished materials A and B.

Material A consists of:
- 50% raw material X
- 20% raw material Y
- 30% raw material Z

Material B consists of:

30% raw material X
10% raw material Y
60% raw material Z

The MFA database has a figure for the input of raw material X, while the USGS database shows that 10% of annual consumption of raw material X is used for producing finished material A. Because material A contains other raw materials too, this does not represent the full mass. The EcoInvent LCA database provides us with the average composition of material A. By determining the percentage weight of material A derived from raw material X, we obtain a figure for the total weight of finished material A.

These data can also be used in the reverse direction.

If LCA data are available for all the main uses of raw material Z (finished materials A and B), we can derive the missing annual flow of basic material Z. This is obviously only feasible if most applications are known.

An additional and potentially important use of this calculation procedure is to validate the applicability of the USGS data.

For a number of finished materials, complete data sets are available: the MFA data on raw material flows, the distribution data on applications of raw materials X, Y and Z and the statistical data on use of finished materials A and B. In such cases the composition of materials A and B and the MFA of X, Y and Z can be used to determine to what extent the USGS distribution data tally. If the data are indeed found to tally reasonably well for a number of different materials, this is an indication that the US data are also valid for the EU, although this is of course no absolute proof.

Data sources used in this study
The environmental impacts of materials consumption were calculated by multiplying the per-kg impacts of the material by volume consumption in the Netherlands. The latter was calculated as domestic production plus imports minus exports. Table 12 reports the sources used for these respective statistics.

table 12 Sources used for production and import/export data

	Production	import/export
sand (filling and bedding sand)	DWW [1]	DWW
cement	CE	CE
concrete	CBS annual statistics	(ignored)
ceramics	CBS annual statistics	Eurostat
Steel	USGS	Eurostat
aluminium	USGS	Eurostat
copper	-	Eurostat
Nickel	-	Eurostat
Zinc	USGS	Eurostat
plastics (PE, PP, PS, PVC)	CE [2]	Eurostat
paper and board	FAO	FAO
Glass	DWW [3]	Eurostat
agricultural products	FAO	FAO

1) DWW: Netherlands Road and Hydraulic Engineering Institute (part of Ministry of Transport, Public Works & Water Management).
2) Plastics production based on naphtha consumption.
3) Glass production based on silver sand consumption.

Fill sand
DWW distinguish filling and bedding sand, concrete and mason sand and silica sand. In assessing the impacts associated with consumption of the material sand, we restricted ourselves to filling and bedding sand, i.e. sand used for bedding and backfilling in road-building and other construction work. This is because the impacts of concrete and mason sand use are part of the life cycles of the materials cement and concrete. The impacts of silica sand (industrial sand), for its part, are included in the life cycle of various other materials, including glass and steel. According to the USGS, silica sand is used as a raw material in a range of materials, including glass (37%), scouring agents (5%), at iron foundries (21%) and in other applications (37%).

Cement
Cement consumption relates solely to consumption of mortar cement (approx. 12%), According to the USGS, some 88% of cement is used for concrete production.

Plastics
For reasons of confidentiality, no production data are available for plastics (CBS, CEREM[35]). As naphtha is the main feedstock for plastics production, kilogram figures for plastics production were derived by multiplying naphtha consumption by an appropriate factor. From the available plastics production statistics a factor 1.2 was deduced. For the per-kg impacts of plastics we used the weighted average of the per-kg impacts of PE, PP, PS and PVC.

Glass
For reasons of confidentiality, no production data are available for glass (CBS, CEREM). Silica sand is the key raw material for glass production. In 1990 Dutch glass production stood at about 980 ktonne (RIVM: SPIN). Consumption of silica

35 Centre for research of economische micro-data, a part of CBS managing confidential data from industries.

sand that year was 1,205 ktonne. Some 37% of this sand is used for primary glass production. However, recycled glass is also fed into the process. After due deliberation we opted to quantify glass production by multiplying silica sand consumption by a factor 0.8 (the ratio between glass production and silica sand consumption in 1990).

References

DWW Pers. comm., Joris Broers, Ministry of Transport, Water Management and Public Works (Road & Hydraulic Engineering Institute).

CE. Minder meten, meer weten!, De Bruyn, S.M. *et al*., 2003.

CBS. Statistische jaarboeken. Centraal Bureau voor de Statistiek. Voorburg/Heerlen

USGS. http://minerals.usgs.gov/minerals/pubs/country/europe.html#nl

FAO. http://www.fao.org/waicent/portal/statistics_en.asp

Eurostat (2001). COMEXT Intra- and extra-EU trade,annual data, combined nomenclature. CD-Rom. ISSN 1017-6594, 2001

E Biomaterials

Use of industrial biotechnology ('white biotechnology') for materials production is seen as one possible strategy for working towards sustainability goals [OECD, 2001]; [EuropaBio, 2003]. In biotechnology, micro-organisms or enzymes are used to catalyse the production process, thereby generally boosting conversion efficiency, i.e. reducing the amount of energy and materials required per unit output compared with traditional chemical processes. A second noteworthy point in our present context is that biotechnology may lead to a shift in consumption from fossil (oil, coal, gas) to renewable feedstocks (plants, wood) as fuels and plastics are developed that are produced from biomass.

Biotechnology is already widely used in the production of fine chemicals (pharmaceuticals, vitamins) and enzymes. From the perspective of materials policy these applications are probably not that relevant, however. Consumption of bulk biotechnological products like biofuels and biopolymers is still only marginal, although this may well change in the coming years.

As fossil energy resources have not been included in this study - the main focus of which is dematerialisation - biofuels have also been omitted from the analysis. Bioplastics are of potential interest, however, and below we briefly examine what changes in environmental impacts might result from increased use of bioplastics made from biomass at the expense of traditional, fossil-based plastics.

Bioplastics

The term bioplastics is used in at least two senses:

1 Plastics produced in an enzyme-catalysed polymerisation process designed to boost process efficiency.
2 Plastics based on renewable rather than fossil resources.

Enzymatic plastics synthesis

The first type of plastics has not been considered in this study. The reasoning here is that technological innovations in production processes occurring over time have been ignored for other materials, too. The LCA database from which the environmental impacts of the materials were taken has process descriptions dating from the time of database construction. To allow for the dynamics of technological innovation over time would require definition of an array of variants for each production process, and a detailed analysis of this nature was not feasible in the present study.

Plastics based on renewable resources (Bio-based plastics)
At present it is mainly fossil resources like oil and gas that are used as feedstocks for plastics (polymers). Bio-based plastics are produced from renewable resources like the sugar dextrose. The first bio-based polymers are already on the market and include Cargill Dow's NatureWorks™ (used for packaging, clothing and electronic appliances) and DuPont's Sorona ® [EuropaBio, 2003].

Much of the research done on use of renewable resources for materials production has been carried out in the United States, one of the key motives being to reduce dependence on oil feedstock. In addition, the US maintains substantial stockpiles of farm produce such as maize, a precondition for low-price production of starch as a raw material for plastics production [OECD, 2001].

In 1999 Monsanto conducted trials with oilseed rape (and several other crops) as a feedstock for a type of bio-based plastic known as PHA (polyhydroxyalkanoate). BASF, too, has experimented with a similar polymer, polyhydroxybutanoic acid, again produced from oilseed rape. In both cases work was put on hold, however, because of concerns about technological and economic viability [OECD, 2001].

Polylactides (PLAs), lactide polymers made from lactic acid, are another example of a new class of plastics made from renewable feedstocks. For some years now lactic acid has been chemically synthesized or produced by fermentation. Recent innovations in the fermentation process have led to a more cost-efficient process and Cargill Dow Polymers (CDP) have built a plant with a production capacity of 140,000 tonne/year for production of polylactide from maize. At the moment this capacity is sufficient to meet global demand for PLA, but new capacity may be built in Europe and Asia in the future.

For its raw material, bioplastics production currently depends on dextrose, a relatively expensive sugar produced mainly from maize in the US and from cereals in Europe. Technologies are presently being developed to enable alternative feedstocks to be used such as sugarbeet (sucrose) or, even cheaper, maize fibre (cellulose) from maize residues, which are currently used as animal fodder. The economic viability of bioplastics production hinges to no small degree on successful utilisation of these latter, cheaper biofeedstocks.

DuPont has developed a bioprocess for producing 1,3-propanediol (PDO) from glucose. A pilot plant has been built to assess the feasibility of an industrial-scale facility producing 90,000 kg/year. There is already a PDO-based polyester polytrimethylene terephthalate (PTT) on the market.

Environmental impacts of bio-based plastics
The PLAs are a group of polymers produced using renewable feedstocks (at present, dextrose from maize) according to the following basic reaction scheme:

fermentation chemical polymerisation
Maize → dextrose → lactic acid → PLA (polylactide polymer)
The key difference between bio-based and traditional plastics lies in the use of biomass crops rather than mined fossil feedstocks. Obviously, this will lead to reduced depletion of fossil fuels and therefore CO_2 emissions, too. Bio-based plastics are compostable, moreover, or may alternatively be incinerated, leaving little residue and at little cost to the environment. On the other hand, though, biofeedstocks bring in an entire new chain of processes upstream of the raw material, as all forms of agriculture involve the use of fertilisers, animal manure, pesticides and energy. This will mean additional impacts under the three headings of eutrophication, acidification and toxicity (eco- and human). In addition, the agricultural chain is also assocated with substantial energy inputs, so that even this mode of plastics production will still be accompanied by depletion of fossil fuel resources and CO_2 emissions. Finally, dedicated biomass production will also mean increased land use.

PLA is used in various applications as an alternative for PET, polyesters (PUR), PS and so on. Depending on the type of plastic substituted, this may lead to a 25-50% decrease in fossil feedstock consumption. If cellulose feedstocks (from straw, bagasse, maize residues) prove viable, a reduction of 80% or more is even anticipated.

During growth, biomass cultivated for plastics production takes up CO_2 from the atmosphere, releasing it again when the plastics decompose or are incinerated. As already mentioned, biomass production requires indirect energy inputs (for fertiliser and pesticide production, among other things) and so there will also be CO_2 emissions. However, net CO_2 emissions are still expected to decrease as biomass replaces fossil resources as a feedstock for synthetic materials production [OECD, 2001].

Bio-based plastics in the Netherlands
There is no information available on Dutch consumption of bio-based plastics. As yet, global production of these materials is modest, with 140,000 tonnes produced annually in the US, most of it presumably for domestic consumption. As there is no production of bio-based plastics in the Netherlands, current Dutch consumption of these materials will be extremely insignificant compared with that of hydrocarbon-based plastics (which in 2000 stood at about 1,000,000 tonnes).

Succesful market penetration of bio-based plastics will depend very much on large-scale supply of cheap biomass. Although cellulose in various forms qualifies as such a feedstock, production technologies are still under development and not yet commercially available.

Against this background, in the present project we have ignored any consumption of bio-based plastics in the Netherlands, but in the realisation that such materials may perhaps become more important in the years ahead.

References

EuropaBio, 2003. White Biotechnology: *Gateway to a More Sustainable Future* EuropaBio, Brussels, Belgium. www.europabio.org

OECD, 2001. *The Application of Biotechnology to Industrial Sustainability* Organisation for Economic Co-operation and Development (OECD), Paris, France.

F Impacts of Dutch fish consumption

Fisheries versus fish farming
There are two basic forms of fish production: harvesting of natural biotic stocks in oceans, lakes and rivers, i.e. fisheries, and fish farming in enclosed facilities. Each has its own specific environmental impacts, due to the different methods and processes employed and the different patterns of materials and energy consumption. These impacts can be summarised briefly as follows:

Fisheries
- Climate change, acidification, etc. due to energy use (boats, refrigeration).
- Biotic resource depletion (due to over-fishing).
- 'Landscape' (i.e. sea-bed) degradation: increased land competition, loss of life support functions, loss of biodiversity (selective species catch, sea-bed damage, etc.).

Fish farming
- Climate change, acidification, etc. due to energy use (water treatment, conditioning, refrigeration).
- Eutrophication and acidification due to use of fertilisers and fish feed.
- Dispersion of toxic substances due to use of pesticides and pharmaceuticals.
- Impacts due to fish feed production (incl. fish meal and oil from wild fish catch and miscellaneous plant and animal products). An average carnivorous farmed fish such as salmon consumes 2-3 times its own body weight in (processed) wild fish. About 10 million tonnes of wild fish are needed to drive current world production of 29 million tonnes of farmed fish (some fish like carp being herbivorous) [Smit, 2003].
- Landscape degradation: increased land competition, loss of life support functions, loss of biodiversity (installation of fish farm facilities, etc.).
- Risk of disease spreading to wild populations.
- Risk of genetic contamination of wild populations.

A number of controversies with respect to fish farming are reviewed in [Luiten, 2003]; [Smit, 2003]; [Anonymous, 2003].

To assess the environmental impacts of Dutch fish consumption, then, the first thing we need to know is how much of that fish is caught in the wild and how much is farmed. In the first case, it will be important to distinguish between fishing methods (trawling, drift-net fishing, etc.) as well as the location of fishing grounds (deep-sea, coastal, etc.). With fish farming, we will need to distinguish between carnivorous and herbivorous species and between farms in open marine waters (sea fish) and in various types of open and closed lagoons (flushed, recirculation, etc.).

In the Netherlands itself, all fish farming takes place in systems where the water is continuously treated and recycled in a closed loop, virtually eliminating eutrophication problems and dispersion of toxics. The risks of spread of disease and genetic contamination are likewise minimal [Luiten, 2003].

Statistics on Dutch fish production and consumption
Although fish farming is an age-old practice, it has recently undergone explosive growth. From 1989 to 1998 production of farmed fish doubled worldwide (over 15% growth annually), while fisheries output remained more or less stable [*Productschap Vis*, 2001]. According to the FAO, between 1987 and 1997 the volume of farmed fish in fact increased almost threefold, from 10 to 29 million tonnes. This means one-quarter to one-third of all the fish consumed today is from fish farms [Smit, 2003]. Other sources report figures of 96 million tonnes of farmed fish compared with 45 million tonnes of fisheries catch [Anonymous, 2003].

At best, wild fisheries output will remain approximately as it stands today. As demand for fish grows with rising world population, it will therefore have to be met increasingly by farm-bred fish. In the Netherlands, too, commercial fish farms are on the increase, with turnover currently standing at approximately 5% that of wild fish catch (excl. crustaceans) [Luiten, 2003].

table 13 International fish farming [Luiten, 2003]

Fish species	Yield (ktonne/year)	Countries
Carp (herbivorous)	8,700	China
Tilapia	700	worldwide
Eel	130	Japan
Trout	130	Norway, Chile, Scotland
Salmon	1,000	Norway, UK, Chile
Sea bream & bass	120	Italy, Greece, Spain, France
Turbot	4	Spain, France

table 14 Fish farming in the Netherlands [Luiten, 2003]

Fish species	Yield (ktonne/year)	no. of fish farms
Eel	3.8-4	60
Catfish	2.2-2.5	25
Trout		5
Turbot & bass	0.15	2
Sole	0.05	1 pilot farm
Tilapia (herbivorous)		under development

table 15 Food balance for aquatic animals in the Netherlands, 1998, '000 tonne [FAO, 2003]

		production	import	stock change	export	supply	feed	seed	processing	waste	other uses
Freshwater fish	animal fats	5.75	55.24	-2.22	23.68	35.09	0		0		0.5
Demersal fish	animal fats	112.91	251.35	0	251.73	112.54	0		-0.81		0
Fish, body oil	animal fats	0	43.61	0	17.35	26.25			0.01		21.13
Fish, liver oil	animal fats	2.6	0.38		2.63	0.35	0.35				
Pelagic fish	fish, seafood	336.93	480.51	0	505.04	312.41	189.74				20
Marine fish, other	fish, seafood	4.13				4.13					4.13
Crustaceans	fish, seafood	12.56	65.57	-8.31	65.39	4.43			0		0
Cephalopods	fish, seafood	0	18.65	0	10.21	8.44					
Molluscs, other	fish, seafood	184.43	49.59	0	113.61	120.4			0		30
Aquatic animals, other	aquatic products, other	0	1.92		0.67	1.24					1.24

Operational characterisation factors for impact calculation

To quantify the environmental impacts resulting from the emissions and other interventions associated with the two varieties of fish supply, we used the baseline impact categories proposed in the 'Dutch' LCA Manual [Guinée *et al*., 2002]. These baseline impact categories are for the environmental problems generally covered by LCAs and for which the manual proposes operational characterisation factors based on Best Available Practice.

The difficulty in assessing the environmental impacts of fisheries and fish farms is that there are no operational factors available for several of the most relevant impacts. Thus, a characterisation model to articulate biotic resource depletion is still lacking and there are no operational factors for loss of biodiversity and life support functions due to landscape degradation. Indeed, the debate on exactly how these categories of impact are to be quantified is still very much ongoing.

A number of studies have examined these impact categories in more detail. [Lindeijer *et al.*, 1998, 2003] and [Köllner, 2000], for example, consider the issue of how the ecological damage associated with various kinds of land use is to be quantified. Before they can be used in LCAs, however, these methods require further development. Even more relevant in the present context is the fact that current models do not yet even include damage to the underwater 'landscape' and ecosystem. [Sas *et al*., 1996] includes a case study used to assess the loss of biodiversity due to marine fisheries. Here again, though, the methodology is still not yet fully fledged, neither does the model encompass the additional ecosystem damage occurring on land. Overall, it would seem, a mature methodology to quantify the direct environmental damage resulting from anthropogenic use of ecosystems, whether terrestrial or marine, is still entirely lacking.

For impacts due to land use, the 'Dutch' LCA Manual [Guinée *et al.*, 2002] recommends using the baseline impact category 'land competition'. The inventory data for land use ('area used' times 'occupation time') are summed without any form of weighting. In other words, a characterisation factor of 1 is taken for all forms of land use. This is expressed mathematically as follows:

'increase of land competition = $a * t * 1$
where a is the area used and t the occupation time. The indicator result is expressed in m_2.yr'.

This indicator might be expanded to the more general notion of 'spatial competition', say, i.e. to include both land and sea. For marine fisheries, this would mean the inventory data being given by the product of the area of the nets used and the time the nets are out. For fish farming, the land competition inventory data for annual fish production, say, would then be the area of the fish farm.

Process data for fisheries and fish farming

Fisheries:
1 LCA food database, Draft [Danish Institute of Agricultural Sciences, 2003]. Mainly energy-related emissions; no interventions like land use or resource extraction. Process data downloadable, using simapro.

Fish farming:
1 LCA food database, Draft [Danish Institute of Agricultural Sciences, 2003]. Mainly emissions due to energy use, feed, formaline, etc.; no interventions like land use or resource extraction. Process data downloadable, using simapro.
2 Fish farming and the environment [Silvenius & Grönroos, 2003].

References
Anonymous, 2003. Vis gaat koe achterna
http://www.veganisme.non-profit.nl/nieuws/a1052427993.htm

Danish Institute of Agricultural Sciences, 2003. LCA food database.
www.lcafood.dk

Guinée *et al.*, 2002. Handbook on Life Cycle Assessment: Operational Guide to the ISO Standards. Kluwer Academic Publishers, Dordrecht, the Netherlands (see also http://www.kap.nl/prod/b/1-4020-0228-9), 2002

Luiten, E., 2003. Controverses rond kweek van vis in Nederland? Stichting Toekomstbeeld der techniek (SST), The Hague, the Netherlands. www.sst.nl.

Silvenius F. & J. Grönroos
Fish farming and the environment
Results of inventory analysis. Finnish Environment Institute, Helsinki, Finland.
(Also available from: www.environment.fi/publications, 2003

Smit, A.
Vissen eten de zee leeg
http://www.animalfreedom.org/paginas/column/astridsmit.html
See also: *Kweekzalm bedreigt de wilde zalm.* Intermediair, 2002.

G 'Top twenties' per impact theme

This appendix reports, for each environmental impact theme, the twenty materials scoring highest with their scores in terms of 'theme-equivalents'.

Although the same set of materials recurs in many of the tables, the order in which they occur is different in each case. There are various (not entirely unexpected) patterns to be observed. Agricultural products, for example, score high on the themes Land competition (because of land use), Global warming (because of the energy intensity of farming), Freshwater and terrestrial ecotoxicity (pesticide use) and Eutrophication (nutrient inputs). Fish proteins also recur under Acidification and Photochemical oxidant formation (ocean transport) and Eutrophication (fish farms). Concrete scores on all the themes, but is seldom high on the list. The same holds for iron and steel and for plastics, all of which feature in the top twenty for all themes. Heavy metals are to be found under Abiotic resource depletion (because of exhaustion of recoverable stocks) and the energy-related themes of Global warming, Photochemical oxidant formation and Acidification. For these themes even the minor flows of noble metals are in the top twenty. Sand and gravel feature under Land competition (because of extraction) and the energy-related themes (because of transport). Despite the quantity involved, sand does not score high on any of the other themes.

Another way of looking at these results is theme by theme, to see which materials are the main contributors in each case. Sometimes a single material accounts for the bulk of the score, as with iron and steel for Abiotic resource depletion and PVC for Ozone layer depletion. It should be borne in mind here that materials are not the only source of the respective environmental problems. As reported in [Van der Voet *et al*., 1993], materials are responsible for between 25% and 50%, and in certain cases more, of individual environmental impacts. In each case the results can provide useful input for thematic policy.

Top twenty, Abiotic Resource Depletion

iron and steel	1.86E+08
paper and board	1.07E+07
aluminium	9.99E+06
concrete	9.77E+06
animal fats	5.44E+06
zinc	3.98E+06
PVC	3.36E+06
copper	2.32E+06
glass	2.30E+06
nickel	1.98E+06
cement	1.55E+06
ceramics	1.38E+06
rockwool	1.29E+06
animal protein	1.26E+06
wood	1.10E+06
sand	9.27E+05
PE	8.81E+05
PP	8.80E+05
starch crops	8.17E+05
PUR	7.34E+05

Top twenty, Land Competition

animal fats	1.10E+10
animal proteins	2.54E+09
starch crops	9.59E+08
sand	6.20E+08
oil crops	4.05E+08
fibre crops for food	2.82E+08
iron and steel	2.72E+08
concrete	2.33E+08
paper and board	1.88E+08
gravel	1.17E+08
aluminium	1.02E+08
wood	9.53E+07
PVC	4.77E+07
protein crops	4.04E+07
ceramics	3.60E+07
copper	3.33E+07
zinc	2.84E+07
animal fibres	2.61E+07
glass	1.88E+07
nickel	1.86E+07

Top twenty, Global Warming

animal fats	1.93E+10
iron and steel	1.90E+10
starch crops	9.50E+09
paper and board	7.88E+09
animal protein	4.46E+09
oil crops	4.01E+09
aluminium	3.37E+09
fibre crops for food	2.80E+09
concrete	2.23E+09
PE(HD)	2.22E+09
PVC	2.05E+09
ceramics	1.52E+09
fish proteins	1.41E+09
PP	1.22E+09
PS	1.19E+09
sand	1.11E+09
glass	8.54E+08
copper	7.95E+08
PUR	7.80E+08
zinc	7.11E+08

Top twenty, Ozone Layer Depletion

PVC	1.32E+05
iron and steel	4.04E+03
paper and board	3.63E+03
PE	3.16E+03
PP	1.78E+03
aluminium	1.73E+03
PS	1.65E+03
sand	1.38E+03
animal fats	1.22E+03
concrete	1.09E+03
fish proteins	1.09E+03
PET	9.70E+02
rubber	6.73E+02
copper	4.91E+02
nickel	3.33E+02
animal proteins	2.82E+02
gravel	2.62E+02
zinc	2.38E+02
PUR	2.15E+02
wood	2.13E+02

Top twenty, Human Toxicity

iron and steel	1.40E+10
zinc	6.67E+09
PET	3.36E+09
paper and board	1.95E+09
lead	1.58E+09
aluminium	1.41E+09
ceramics	1.40E+09
PE	1.33E+09
animal fats	8.93E+08
PS	7.20E+08
PP	7.16E+08
nickel	6.60E+08
PVC	6.49E+08
concrete	6.18E+08
copper	3.32E+08
glass	2.14E+08
PUR	2.08E+08
animal proteins	2.06E+08
rubber	1.70E+08
sand	1.40E+08

Top twenty, Aquatic Ecotoxicity

animal fats	4.51E+09
iron and steel	2.65E+09
animal proteins	1.04E+09
starch crops	8.14E+08
nickel	5.98E+08
oil crops	3.44E+08
paper and board	3.11E+08
fibre crops for food	2.40E+08
aluminium	1.66E+08
zinc	1.50E+08
concrete	1.29E+08
PE	1.17E+08
PP	6.78E+07
PVC	5.52E+07
PS	3.67E+07
barite	3.49E+07
protein crops	3.43E+07
PET	3.28E+07
glass	3.09E+07
copper	2.47E+07

Top twenty, Marine Ecotoxicity

ceramics	1.87E+13
iron and steel	1.32E+13
aluminium	7.65E+12
paper and board	3.03E+12
glass	1.30E+12
animal fats	1.14E+12
PE	9.33E+11
nickel	8.76E+11
PVC	8.65E+11
zinc	7.99E+11
concrete	7.62E+11
PP	4.40E+11
copper	4.10E+11
PS	2.99E+11
PUR	2.77E+11
animal proteins	2.64E+11
wood	2.45E+11
sand	2.44E+11
rubber	1.97E+11
rockwool	1.82E+11

Top twenty, Terrestrial Ecotoxicity

animal fats	1.91E+08
zinc	8.04E+07
raw iron	7.24E+07
paper and board	5.65E+07
animal proteins	4.40E+07
PE	3.49E+07
starch crops	3.31E+07
aluminium	1.96E+07
oil crops	1.40E+07
PVC	1.30E+07
PP	1.12E+07
fibre crops for food	9.74E+06
lead	9.22E+06
concrete	8.39E+06
PS	6.95E+06
nickel	6.03E+06
PET	3.94E+06
PUR	3.44E+06
rubber	2.64E+06
wood	2.39E+06

Top twenty, Photoch. Oxidant Formation

iron and steel	1.00E+07
PE	7.27E+06
nickel	4.48E+06
paper and board	2.73E+06
animal fats	2.55E+06
copper	1.03E+06
aluminium	9.64E+05
rubber	9.16E+05
concrete	7.61E+05
PP	5.97E+05
animal proteins	5.89E+05
PVC	5.23E+05
rockwool	5.12E+05
fish proteins	5.06E+05
sand	3.61E+05
ceramics	3.47E+05
PS	3.30E+05
zinc	3.15E+05
platinum	3.12E+05
palladium	2.18E+05

Top twenty, Acidification

nickel	1.11E+08
animal fats	9.87E+07
iron and steel	6.77E+07
paper and board	5.65E+07
copper	2.45E+07
animal protein	2.28E+07
aluminium	2.02E+07
concrete	1.09E+07
PP	1.02E+07
PE	9.30E+06
PVC	9.28E+06
fish proteins	8.15E+06
platinum	7.76E+06
zinc	6.26E+06
ceramics	5.97E+06
palladium	5.44E+06
sand	5.39E+06
PS	4.97E+06
PUR	3.22E+06
wood	2.70E+06

Top twenty, Eutrophication

animal fats	1.21E+09
animal proteins	2.81E+08
starch crops	2.57E+08
oil crops	1.08E+08
fibre crops for food	7.55E+07
protein crops	1.08E+07
fish proteinss	8.09E+06
iron and steel	5.07E+06
animal fibres	2.88E+06
paper and board	2.06E+06
concrete	1.62E+06
PP	1.22E+06
aluminium	7.61E+05
sand	7.22E+05
fibre crops for clothing	6.62E+05
ceramics	6.54E+05
PE	3.65E+05
PVC	3.52E+05
wood	3.03E+05
zinc	2.91E+05

Top twenty, Ionising Radiation

iron and steel	4.87E+00
paper and board	4.85E+00
aluminium	3.36E+00
animal fats	3.15E+00
PVC	1.99E+00
concrete	1.39E+00
copper	1.22E+00
zinc	1.12E+00
ceramics	8.72E-01
wood	7.32E-01
animal protein	7.29E-01
nickel	7.26E-01
sand	6.52E-01
PE	5.49E-01
PP	5.49E-01
PUR	4.76E-01
starch crops	4.57E-01
rubber	4.30E-01
PS	3.99E-01
glass	2.93E-01

Top twenty, Final Solid Waste

concrete	3.47E+10
iron and steel	1.40E+10
starch crops	4.15E+09
ceramics	4.13E+09
animal fats	3.75E+09
oil crops	1.75E+09
fibre crops	1.22E+09
glass	1.19E+09
animal proteins	8.66E+08
cement	7.59E+08
aluminium	6.06E+08
gypsum	5.50E+08
copper	4.91E+08
paper	4.60E+08
rockwool	2.51E+08
zinc	2.43E+08
fish proteins	2.24E+08
protein crops	1.75E+08
water	1.51E+08
PVC	1.10E+08

H Description of impact assessment and weighting methods

Problem Oriented Approach and Eco-indicator 99
The Problem Oriented Approach (CML method) forms the basis for both equal weighting and the NOGEPA weighting scheme. The basic point of departure is that all environmental interventions are translated into terms of their potential contribution to well-defined categories of environmental impact. To obtain an overall score, these impact scores must then be weighted and summed. The Eco-indicator 99 method is based in the same principles, but employs different impact categories, defined as final variables (damage to…) rather than mid-point variables (acidification, eutrophication and so on, i.e. the Dutch policy themes). This has pros and cons. The Eco-indicator involves automatic weighting, moreover, while the Problem Oriented Approach involves no intrinsic weighting, this being carried out as an explicit step.

The tables below list the normalisation factors and weighting factors for the Problem Oriented Approach (equal weighting as well as NOGEPA weighting) and Eco-indicator 99. Normalisation is a step that must be carried out prior to weighting, in which the contribution of the functional unit in question is related to global emissions and extractions per problem or damage category. In this way the various problems can be included under one and the same heading, as it were.

table 16 Normalisation and weighting factors: Problem Oriented Approach

		ADP	LUC	GWP	ODP	HTP	FAETP	MAETP	TETP	POCP	AP	EP	Radiation	FSW
normalisation factor		1.57E+11	1.24E+14	4.15E+13	5.15E+08	5.71E+13	2.04E+12	5.12E+14	2.69E+11	9.59E+10	3.22E+11	1.32E+11	1.34E+05	7.33E+12
weighting factor	NOGEPA	0.00	0.00	0.35	0.05	0.18	0.07	0.00	0.05	0.09	0.07	0.14	0.00	0.00
		0	0	32	5	16	6		5	8	6	13	0	0
	equal	0.10	0.10	0.10	0.10	0.03	0.03	0.00	0.03	0.10	0.10	0.10	0.10	0.10
		1	1	1	1	0.33	0.33		0.33	1	1	1	1	1
	shadow price	0.00	0.00	0.00	0.66	0.00	0.00	0.00	0.00	0.05	0.09	0.20	0.00	0.00
		0	0	0.05	30	0.09	0.03		0.06	2.14	4	9	0	0.185

table 17 Normalisation and weighting factors: Eco-indicator 99

	HUMAN HEALTH						ECOSYSTEM HEALTH				RESOURCE DEPLETION	
ECOINDICATOR99	Carcin.	Resp.org.	Resp.inorg	Climate ch	Radiation	Ozone laye	Ecotox	Acid.+eutr.	Land occ.	Land conv.	minerals	fossil fuels
normalisation factor	1.54E-02	1.54E-02	1.54E-02	1.54E-02	1.54E-02	1.54E-02	5.13E+03	5.13E+03	5.13E+03	5.13E+03	8.41E+03	8.41E+03
weighting factor	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.2	0.2

Below, in the following passage taken from the LCA Handbook, the two methods are explained on more detail and compared and contrasted.

In the Netherlands two Impact assessment methods have been developed in the last decade, both grounded in the 'environmental themes' formulated by the Dutch Government in 1989 [VROM, 1989]; [RIVM, 1991]. Both have the same basic structure, with the indicator results obtained by multiplying the inventory results by the appropriate characterisation factor together forming the so-called environmental profile, which is then normalised, before serving as input for a possible weighting step. Where the two methods vary is with respect to the characterisation models and characterisation factors developed and proposed for the individual themes.

In terms of their operationalisation there are also several clear differences between the methods. The first method, often referred to as the problem-oriented approach and first presented by [Heijungs *et al*., 1992], operationalised models and characterisation factors for a number of impact categories, but did not operationalise the weighting step. The second Dutch method is the Eco-indicator approach, developed primarily for use in Design for the Environment (DE) initiatives. Designers were deemed unable to work with 10-20 indicator results, and the Eco-indicator therefore employs only 1 to 3 weighted indices. Thus, there is greater emphasis on weighting than in the approach of [Heijungs *et al*., 1992]. In the first version of the Eco-indicator [Eco-indicator 95; Goedkoop, 1995] weighting was based partly on a damage approach, partly on a distance-to-target approach (i.e. based on predefined damage targets). Most of the impact categories identified were adopted from [Heijungs *et al*., 1992] although the two toxicity themes were defined rather more narrowly.

Originally conceived as an experiment, the Eco-indicator method has since been improved. In the latest version [Eco-indicator 99; Goedkoop & Spriensma, 1999] a completely different approach to Impact assessment has been adopted in which a limited number of damage categories are weighted (by a panel of experts, for example). Three types of damage are distinguished, for which weighting is taken to be more readily feasible:

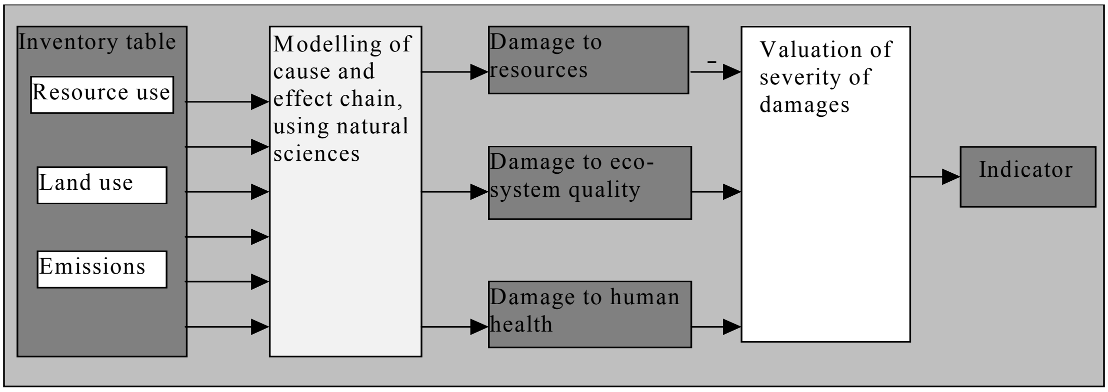
- Damage to resources.
- Damage to ecosystem quality.
- Damage to human health.

As in the problem-oriented approach, the natural sciences are used to calculate the relation between the impacts of a (product) system's life cycle and the resultant damages. The Eco-indicator methodology thus consists of two parts:

- Scientific calculation of the three forms of damage due to the life cycle of the product under study.
- A valuation procedure to establish the significance of these damages.

The method has a modular structure [here: Figure 41] in which the building blocks of the natural science component can be modified or replaced to reflect different value systems (viz. Egalitarian, Individualist, Hierarchist). The authors recommend using the Hierarchist version of the model as the default method, with the other two being run as a form of sensitivity analysis [Goedkoop & Spriensma, 1999].

figure 42 The modules of the Eco-indicator 99 method (source: [Goedkoop, 1997])



In the Eco-indicator 99 approach, 'damage to health' is operationalised using the notion of DALYs: Disability-Adjusted Life Years. This indicator is said to measure 'the total amount of ill health, due to disability and premature death, attributable to specific diseases and injuries. The DALY concept thus compares time lived with disability (YLD: Years Lived Disabled) ands time lost due to premature mortality (YLL: Years of Life Lost). Health is simply added across individuals. That is, two people each losing 10 years of disability-free life are treated as the same loss as one person losing 20 years' [Goedkoop & Spriensma, 1999]. For the technical details of the DALY concept, the reader is referred to (Box 4.1) of this publication.

Both the problem-oriented approach and the Eco-indicator approach conform to the ISO 14042 (2000E) framework, as reflected in ISO/TS 14047 (in prep.), since both clearly distinguish the characterisation and weighting steps.

Although the Eco-indicator 99 approach is very promising and certainly appealing as an avenue for further research, the problem-oriented approach is currently considered the 'best available practice' for Impact assessment and has therefore been adopted in this Guide. The Eco-indicator method still has several serious shortcomings. It includes far fewer inventory items and provides only very limited coverage of human-toxic impacts (carcinogenicity only, thus ignoring a wide range of other health impacts). Some of the constituent models are outdated compared with those now used in the problem-oriented approach, while others involve major uncertainties. Thus, the terrestrial acidification and eutrophication models are based on the local, Dutch situation, while the problem-oriented approach now uses a European model [Huijbregts, 1999b]; the data and assumptions of the toxicity model can be improved (cf. [Huijbregts 1999a]); and linkage of GWP and ODP and other universally accepted factors to damage parameters is still very incomplete and uncertain. Finally, aggregation of ecotoxicological impacts with eutrophying, acidifying and land use impacts is still very preliminary, and the ecosystem impacts of climate change, increased UV radiation and photochemical smog are not yet included.

The key feature of the problem-oriented approach is that the category indicators are defined at midpoints along the environmental mechanism, congruent with current environmental policy themes, and can therefore be modeled relatively accurately. The approach has the added advantage of permitting flexible choice of characterisation model and position of category indicator in the environmental mechanism, since for many impact categories more than one model is defensible and available. However, midpoints (wherever their precise position in the mechanism) are a difficult input for weighting and in the problem-oriented approach there is thus still no set of weighting factors covering all impact categories.

The main advantage of the Eco-indicator 99 is that category indicators are defined at the endpoint level, giving them greater environmental relevance. As it is this level that ultimately matters to society, the object of the weighting procedure is more immediate. The major uncertainties associated with modeling from midpoints to endpoints constitute a serious drawback, however.

Environmental priority systems (EPS)

The following description of the EPS method is taken from a report published in 1998. Although the principles remain unchanged, the array of extractions and emissions has since been extended.

The EPS method [Steen, 1996 and 1993] is an evaluation method based on environmental economics. In the classification step the interventions (emissions, extractions etc.) are grouped together into a number of damage types. In EPS the damage types are grouped into five ‘safeguard subjects’: Resources, Human Health, Aesthetic Values, Ecosystem Resilience and Ecosystem Production Capacity. A set of weighing factors, ‘Enviroaccounting factors’, is applied directly to the emissions of substances and extractions of resources. In the 1996 version of EPS, these ‘Enviroaccounting factors’ are split up in characterisation and valuation factors. It is however not transparent how the factors have been derived.

In the characterisation step the actual damage on each of the damage types is determined following the SETAC concept of classification and characterisation combined with some correction factors such as the extension in area or persons influenced by the effect, the intensity and frequency of the occurrence of a problem, the durability of a problem. The quantitative contribution from various interventions to the damage types described as number of ‘unit effects’ rather than CO_2-equivalents or similar. A unit effect is a measurable impact (end point effect) which has a specified extension in time, space and intensity, for instance ‘one man-year of moderate morbidity’. The linkage between an emission and the unit effects can be modelled and checked in a scientific way. Resources are used as separate damage types. For Human Health five damage types are chosen: mortality, severe morbidity and suffering, morbidity, severe nuisance and moderate nuisance. The impact category of the safeguard Ecological Health is based upon the number of endangered species.

The valuation of the interventions is then performed in monetary terms. The monetary value of the safeguard subjects is calculated, based on actual

expenditures taken by society to avoid/restore damage or on contingent valuation ('willingness to pay' to avoid negative effects). EPS requires a quantification of damage. EPS is an explicit valuation method which tries to 'scientifically' measure prices and social preferences that exist independent of the process of analysis. The valuation is based on a generic assessment and not on local conditions [Hertwich *et al*, 1996].
The characterisation and valuation are combined in an 'Enviroaccounting factor'. The EPS Enviroaccounting factors are expressed in ELU (Environmental Load Units) per kg substance. This unit is assumed to be equal to ECU but it is called in a different way because it does not represent a real market value but a common value that can be used to compare different measures.
The Enviroaccounting factors for emissions is given by the multiplication of five factors:
EAem: $\sum(F_1{*}F_2{*}F_3{*}F_4{*}F_5)$
where:
F_1 is the society monetary value of the unwanted changes to each safeguard subject.
F_2 is the extension in area or persons influenced by the effect.
F_3 is the intensity and frequency of the occurrence of a problem.
F_4 is the durability of a problem.
F_5 is the contribution of a substance to a problem.

The Enviroaccounting factor for resources (EAres) is given by the present and future generations willingness to pay to restore the reserves. The estimation of the value is based on the environmental costs necessary to gain the minerals or the fossils from other rocks or sources with the help of biotic energy source.

The Enviroaccounting of a total set of emissions and extractions is given by:
$EA= \sum (EAem,_{i} * Q_i) + \sum (EAres,_{i} * R_i)$
where;
Q_i is the quantity of the substance i
R_i is the quantity of the resource i
The EPS focuses more on resource depletion as compared to emissions.

table 18 Pros and cons of the EPS method

Major strengths	Major weaknesses
• An attempt to valuate damages in monetary terms.	• The method is not transparent. • Only a very limited group of interventions can be valuated. • It is not clear which mechanisms are considered, if fate and exposure aspects are considered etc., etc. • The main focus is on resource depletion, with little to no attention given to ecosystem health not related to production capacity.

table 19 Safeguard subjects and damage types in EPS

Safeguard subject	Damage types	Unit
Resources	Decrease of present oil reserves	1 kg
Resources	Decrease of present coal reserves	1 kg
Resources	Decrease of present Ag reserves	1 kg
Resources	Decrease of present Al reserves	1 kg
Resources	Decrease of present As reserves	1 kg
Resources	Decrease of present au reserves	1 kg
Resources	Decrease of present bi reserves	1 kg
Resources	Decrease of present cd reserves	1 kg
Resources	Decrease of present co reserves	1 kg
Resources	Decrease of present cr reserves	1 kg
Resources	Decrease of present cu reserves	1 kg
Resources	Decrease of present fe reserves	1 kg
Resources	Decrease of present hg reserves	1 kg
Resources	Decrease of present mn reserves	1 kg
Resources	Decrease of present mo reserves	1 kg
Resources	Decrease of present ni reserves	1 kg
Resources	Decrease of present pb reserves	1 kg
Resources	Decrease of present pt reserves	1 kg
Resources	Decrease of present rh reserves	1 kg
Resources	Decrease of present sn reserves	1 kg
Resources	Decrease of present ti reserves	1 kg
Resources	Decrease of present u reserves	1 kg
Resources	Decrease of present v reserves	1 kg
Resources	Decrease of present w reserves	1 kg
Resources	Decrease of present zn reserves	1 kg
Resources	Decrease of present zr reserves	1 kg
Human health	Excess mortality, normalised	1 case
Human health	Painful morbidity or severe suffering	1 man year
Human health	Other morbidity	1 man year
Human health	Severe nuisance	1 man year
Human health	Moderate nuisance	1 man year
Production capacity	Decrease of meat or fish	1 kg
Production capacity	Decrease of wood growth	1 kg
Production capacity	Decrease of base cation reserves	1 case
Production capacity	Less fresh water in areas of water deficiency	1 kg
Production capacity	Decreased crop growth	1 kg

Table 20 lists the EPS impact factors / weighting factors for selected materials.

table 20 EPS impact factors / weighting factors for selected materials

EPS	weight
rhodium	4.95E+07
platinum	7.45E+06
palladium	7.44E+06
nickel	170
copper	126
lead	92.9
chromium	91.5
zinc	64
refrigerant R22	15.7
refrigerant R134a	15.3
mamganese	7.05
aluminium	6.3
PUR	3.66
PET	3.14
PC	2.64
PP	2.63
PS	2.55
iron and steel	2.41
PVC	2.11
rubber	1.8
PE	0.799
trout (fish farming)	0.595
pelagic fish	0.447
shellfish	0.431
paper and board	0.396
glass	0.366
rockwool	0.305
animal biomass	0.278
H2SO4	0.262
soda	0.192
demersal fish	0.142
plant biomass	0.0965
barite	0.0872
NaCl	0.0684
ceramic	0.0621
cement	0.0583
gypsum	0.053
gravel	0.0023
limestone	0.00207
sand	0.00138
concrete	-0.00232
water	-0.00918
wood	-0.0664

I Calculating the environmental impact of individual materials

For the *extraction and production* phase of the life cycle of each material we used cradle-to-gate data from the EcoInvent database, which already has data on far more materials than its predecessor, the ETH database. It is built up around a large number of processes, most of them production processes, with all their associated inputs and outputs. More specifically, the database has figures for physical production inputs and outputs (raw materials, other materials, products) and environmental inputs and outputs (extractions and emissions). By combining processes, a process tree can therefore be created for a functional unit, here taken as 1 kilogram of the material. Using the database, all the processes involved in producing that kilo are thus specified and quantified. The software then produces an 'ecoprofile': a list of all emissions and extractions as well as claims on land and quantities of final waste from cradle to *gate* (rather than grave). This ecoprofile is then fed into the next stage of the calculation process: the LCIA, or Life Cycle Impact Assessment, which converts the ecoprofile into contributions to the various environmental impact categories. The eventual output is a comprehensive picture of the environmental burden associated with the material down the production part of the chain.

For the *use* phase no such standardised data is available, not for all materials at any rate. This is undoubtedly due to the vast array of products in which each material may ultimately be used. We adopted a simplified, pragmatic course of action to gain at least a rough indication of the emissions associated with the material during the use phase of the life cycle. Other aspects, like the energy consumption of appliances for which the material is used, were ignored. This would seem appropriate as the energy requirements of products are not inherent in the materials from which they are manufactured.

This simplified approach runs as follows. With respect to emissions during the use phase, three basic categories of materials can be distinguished:
1 Materials with no emissions in usage.
2 Materials with modest usage emissions.
3 Materials entirely emitted during usage.

Materials of the first type include glass, wood and concrete. The implicit assumption here is that there is no wear and tear or corrosion in use and that the material in its entirety ends up in the final waste phase.

Materials of the second type do undergo wear and tear and corrosion or other forms of leaching or leakage during use. Examples include metals exposed to the air and thereby corrode, leaching some fraction of the metal to the environment. There are two problems here. First, it depends not only on the material but also on the application whether or not corrosion occurs. In electronic applications copper does not corrode, for example, while it does when used for water pipes. In the case of these ‘type 2’ materials, then, it will be necessary to consider the precise application involved. A second problem are quantitative data on leakage rates, which are not available for all materials of interest, by any means, and are often uncertain at best for various reasons. Here we therefore had to make several simplifying assumptions.

For ‘type 3’ materials there is simple equality between consumption and emission. Key examples include solvents, artificial fertilisers and pesticides.

For the *waste* phase, for each material we needed to specify the split between landfill, incineration and recycling/reuse. Although in part (the split between landfill and incineration, for example) this is policy-driven, it also depends to some extent on the material. In the case of most metals, for instance, the percentage recycled is high. Recovery is fairly straightforward as well as profitable, given the relatively high price of these materials. Plastics recycling has been a policy goal for some time now, but is not getting off the ground because of difficulties with waste collection. In the case of plastics, incineration is not that bad an alternative, because energy can be recuperated. Stonelike building materials, to the extent they are not recycled, are landfilled almost in their entirety as they cannot be burned.

The LCA database has figures on waste disposal for certain materials and these were then used to estimate the environmental interventions associated with the final waste phase. Where the database lacked such data, we had to make our own assumptions about this terminal phase of the life cycle.

Recycling is an issue in its own right. Not only is it a type of waste disposal; it also affects the extraction and production phase. The greater the amount of recycled material available, the less virgin material will be required. It is no simple matter to establish a recycling rate for individual materials, particularly as part of the supply chain is located outside the Netherlands. On this point the LCA database makes assumptions for certain materials, involving particular choices with respect to allocation. For some materials, for example, an assumption has been made about the percentage of recycled material fed into the material supply chain. For other materials, a ‘primary’ and ‘secondary’ grade of material are distinguished (specifically for aluminium and copper). For plastics, the assumption is that they are all incinerated, but with energy recuperation, itself a form of ‘recycling’. Although these assumptions are not always consistent, we opted to go along with them, as it was beyond the scope of the present project to establish an accurate recycling rate for each individual material.

J Review of sectoral waste policies

Sectoral waste policy

Building & demolition

The sectoral plan for the building industry elaborated under the terms of the National Waste Management Plan (LAP) sets out a number of policies relating to materials consumption, most of them regulatory in nature, as described below.

Using LCA methodology, the Netherlands Normalisation Institute (NEN) has developed a method for quantifying environmental impacts at construction-site level, yielding a 'Materials-related Environmental Profile'. The environment ministry VROM had hoped to have this operational by the end of 2003, after which a decision could be made on whether the method could serve as a basis for legislation (for inclusion in the **Building Decree**). Basic legislation and associated regulations would then have been published by the end of 2003 or early 2004. For lack of support for the Profile, however, in spring 2003 NEN disbanded the committee working on the issue. This policy could have achieved both dematerialisation and substitution, but was unfortunately not implemented.

The **Building Materials Decree** lays down standards on materials, particularly on the use of stone- and brick-like building materials. The decree seeks to reduce the impact of such materials on the quality of groundwater and surface water and encourage use of secondary materials. The **Regulation on non-recyclable and non-incinerable building and demolition waste** stipulates that building and demolition waste may only be landfilled if it has been designated non-recyclable and 'non-incinerable'. This may be the case if such waste is so contaminated as to make incineration or useful application technically unfeasible or undesirable for public health reasons. In practice, the main contaminants are polycyclic aromatic hydrocarbons (PAH) and asbestos.

Under the **Waste Substances (Prohibition of Landfill) Decree** several categories of building and demolition waste may not be landfilled: (unsorted) building and demolition waste and residues from its processing (category 19), filter sand (20), blasting grit (21) and wood waste (22).

Besides the above policies, the **LAP** sectoral plan also includes minimum standards of disposal for various building materials. Finally, the **IFD programme** promotes industrial and 'flexible' construction methods facilitating ultimate disassembly (rather than demolition) of buildings. The sectoral plan mentions no specific policies for securing these aims, though they will probably take the form of subsidies.

The main effect of the cited policies is in the area of recycling.

Besides the sectoral plan, until recently there was also the **Sustainable Building Programme** (DuBo programme) which sought to reduce materials consumption and promote the use of alternative (sustainably produced) materials. Although this programme has now been discontinued, some of the constituent policies are to remain in force. Two in particular merit attention here: the Green Mortgage scheme and 'covenants' on public housing construction (which run through to 2005).

Green Mortgage scheme
Under the **Green Mortgage scheme**, part of the so-called Green Projects programme, owners of new or renovated dwellings satisfying certain criteria regarding materials usage (among other things) are eligible for a lower interest rate on their mortgage. These criteria relate mainly to the kind of materials used, with very specific requirements set on wood, concrete and plaster with respect to 'sustainability' of production. What we have here, then, is substitution of traditional materials for (more) sustainable alternatives. Besides these criteria, the Green Mortgage scheme also has requirements on optimal piping grid length, which will also have some dematerialisation impact.

Covenants on public housing schemes
The government has established a series of covenants, i.e. negotiated agreements, with the public housing sector, generally at the local or regional level, with the aim of promoting 'sustainable housing'. The main feature are criteria on the energy performance of individual houses. This is also basically the case with the **National Dwelling Agreement**. As arrangements may also be made on the use of environmentally benign building materials, though, there will be some measure of impact on substitution.

→ Main effect: (profile) substitution, recycling

Packaging
Dutch implementation of European Directive 94/62/EC on packaging and packaging waste is shown schematically in table 21.

table 21 Implementation of Directive 94/62/EC in the Netherlands

Environmental Management Act	
Regulation on Packaging and Packaging Waste	
3rd Packaging Covenant	Targets for total packaging waste, decoupling and recycling percentages

Although this Directive is concerned solely with recycling, Dutch policy goes further and seeks to achieve dematerialisation as well as decoupling. How this is to be done is set out in the 3rd Packaging Covenant (PC-3), which also provides targets for 2005 for the total amount of packaging marketed (by weight), for recycling rates for the various materials, and for relative decoupling from GDP (67%). The main goal of this covenant is to reduce the amount of waste requiring final disposal, with progress being measured in terms of the volume (weight) of waste remaining in that category. One side-effect of this may therefore be a trend towards heavier materials being substituted for lighter (e.g. plastics for glass).

PC-3 covers the following materials: metals (steel and aluminium), paper and board, plastics and glass. A subsidiary covenant has also been agreed for wood, but in contrast to the other materials no target has been set. The first four (groups of) materials feature in the ‘top 20’ selected for review in the present study.

Table 22 shows the quantity of each category of packaging marketed annually in the Netherlands and the share of each in the aggregate Dutch flow of the material in question (both in terms of apparent consumption). The table also shows the current recycling rates cited in the covenants and the targets for 2005 (when PC-3 expires).

table 22 Packaging data cited in 3rd Packaging Covenant, 2000

	ktonne marketed	% of total material flow in packaging	recycling %	2005 target %
Paper/board	1,382	35	72	75
Glass	519	70	78	90
Metals	216	3.4	77	80
Plastics	494	14	37	45

For glass and paper/board, PC-3 aims to achieve recycling of a significant percentage of the overall flow (25-55%). In the case of glass, it is only glass packaging that is collected and recycled.

In the case of metals and plastics, the fraction of the overall material flow used for packaging is too small for there to be any major impact (3-5%). In addition to the recycling target for each material, there is also a target for the maximum quantity of waste requiring final disposal due to Dutch packaging use. Besides recycling, this will also lead to greater materials efficiency (less weight per packaging unit) as well as substitution, mainly through replacement of glass and metals by plastics. Again, it is to be queried whether this substitution will reduce environmental impact. However, the overall effect of substitution is difficult to quantify in terms of either weight or environmental impact.

All in all, then, there is likely to be a direct and, for some materials, substantial impact on recycling and to a lesser extent dematerialisation. It is also of interest that the Packaging Covenant also explicitly seeks to achieve macro-economic decoupling relative to GDP. Although there will be a degree of materials substitution as an unintended side-effect, the resultant changes in environmental impact need not be gains, as substitution is weight-driven.

→ Main effect: recycling, dematerialisation
→ Unintended effect: substitution

Paper/board
In the case of paper and board, roughly half the total material flow is used for packaging. The same recycling targets have been set for the overall flow as for paper and cardboard packaging. Separate collection of this waste fraction is the responsibility of municipal authorities (as provided for under both LAP and PC-3).

→ Main effect: recycling

Plastics
The sectoral plan for plastics includes several policies of relevance here, all of them regulatory. The Agricultural and Horticultural Sheeting (Disposal) Decree stipulates that after the year 2000 70% of such sheeting is to be recycled/reused, with 15% prevention achieved relative to projected supply in that year. The Waste Substances (Prohibition of Landfill) Decree already prohibits landfilling of most kinds of plastic waste. For separately collected plastics waste from the rubber and plastics industry, agricultural and horticultural sheeting, plastics in building and demolition waste, plastics in scrapped vehicles, plastics packaging and long-cycle PVC products, the minimum disposal standard is useful application in the form of materials recycling. Production scrap and non-recyclable plastics waste must be incinerated. In this latter case energy is recuperated, keeping net greenhouse gas emissions relatively low (which should be duly factored into the indicator). It should also be noted that recycling is not always the best option in terms of environmental impact.

→ Main effect: recycling

Textiles
The sectoral plan for textiles waste comprises economic as well as regulatory instruments. The LAP policy framework stipulates that 50% separate collection of all textiles waste by 2006. A subsidy scheme (*Subsidieregeling Aanpak Milieudrukvermindering*) has been introduced to support producers in pursuing this target. The minimum disposal standard for separately collected textiles waste is useful application in the form of materials recycling. Production waste, non-recyclable textiles and non-marketable recyclable textiles may be disposed of in waste incinerators.

→ Main effect: recycling

Metals
The minimum disposal standard for metal wastes (under Sectoral Plan 21) is materials recycling of the recovered fraction. Production scrap and non-recyclable metals are to be disposed of.

In the case of ferro-metals, including most tins, the materials can be readily separated from household waste and require no dedicated separation system or consumer effort. In this respect, this flow differs from those of glass, paper and plastics.

→ Main effect: recycling

Overview of separation rates

Industrial waste

The sectoral plan for process-related[36] industrial waste prescribes useful application of 90% of such waste by 2006. In tonnage terms, the main waste flows

involved are scrap, slag and loose dirt (on crops). When it comes to useful application, it is only blast furnace slag (for cement production and road-building) that is relevant for the selection of materials reviewed here (*cf.* section 1.1.2). Besides the 90% target for useful application, the sectoral plan also seeks to achieve relative decoupling (though no quantitative goal is cited). With industrial waste, the main scope for prevention lies in improving the materials efficiency of key processes, which will reduce both materials throughput and waste flows. The direct result will therefore be dematerialisation.

→ Main effects: substitution (of building materials), dematerialisation

Office, shop and service waste

Office, shop and service waste, equivalent in composition to the 'residual' fraction of household waste, derives from retailers/wholesalers, offices and other commercial as well as government establishments. In this case the sectoral plan comprises both economic and regulatory instruments. Prevention is regulated under operating licenses or by General Administrative Order (under section 8.40 of the Environmental Protection Act). The aforementioned subsidy scheme (*Subsidieregeling Aanpak Milieudrukvermindering*) is available to municipalities (possibly acting in concert) to encourage waste prevention and separation at licensed industries and industries covered by these 'Section 8.40 GAOs'.

→ Main effect: unknown

[36] Process-related industrial waste is covered by the sectoral plan for office, shop and service waste.

K Review of specific product policies

End-of-life vehicles
In the Netherlands the European End-of-Life Vehicles Directive (2000/53/EC) has been implemented as summarised in table 23.

table 23 Implementation of Directive 2000/53/EC in the Netherlands

End-of-Life Vehicles Decree	Ban on lead etc. Producer and importer duties with respect to prevention, take-back and disposal, at no cost to consumers	2007 95% useful application (incl. product reuse) and 85% product and materials recycling	End-of-life vehicles comprise 74% metal, 5% rubber, 11% plastics, 3% glass and 7% misc. fluids
End-of-Life Vehicles Regulation	Reporting and monitoring		
Revision of Vehicle Registration Regulation			
National Waste Management Plan (LAP)			

The LAP sectoral plan for end-of-life vehicles sets out provisions for waste prevention and criteria for vehicle processing and final disposal of components and residues. The policy instruments relevant to materials consumption are regulatory in nature. In addition, the Waste Substances (Prohibition of Landfill) Decree prohibits any landfilling of vehicle scrap or scrap tyres.

Under the Tyres (Disposal) Decree of 17 March 2004, producers and importers of vehicle tyres have a duty to take back and process tyres at the end of their service life. At the moment 40% of tyres are patched up, 30% incinerated, 20% ‘usefully applied’ and 10% recycled.

For this product group, then, the following policies are in place: prevention, reuse/ recycling targets, compulsory take-back by producers/importers and a ban on landfilling.

White and brown goods
European Directive 2002/96/EC on Waste Electrical and Electronic Equipment (WEEE), covering most domestic appliances and equipment (‘brown and white goods’), seeks to reduce the volume of waste requiring disposal by means of prevention, reuse, recycling and other forms of useful application.

table 24 Directive 2002/96/EC

Policy schedule	13 February 2003	Targets
	31 December 2003	'Useful application' per type of appliance: 80% w/w large domestic appliances, vending machines 70% w/w small domestic appliances, lighting units, electric and electronic equipment, toys, sport and recreational appliances, measurement & control apparatus 75% w/w computer/telecom equipment, consumer appliances
	31 December 2003	Reuse and recycling of components/materials: 80% w/w fluorescent lighting 75% w/w large domestic appliances, vending machines 50% w/w small domestic appliances, etc. 65% w/w computer/telecom equipment, consumer appliances
Implementation in national legislation	13 August 2004	
Deadline for introduction of collection and take-back systems	13 August 2005	
Deadline for securing target of at least 4 kg separated/collected WEEE per capita	31 December 2006	
Commission reports to Council and European Parliament	13 February 2008	

There is as yet no obligation to implement this Directive in national legislation, but in the Netherlands no changes are anticipated to the policies already in force, which under the LAP sectoral plan are as follows. Retailers, on sale of a new product, are obliged to take back an equivalent product 'at no extra cost'. In addition, municipalities have a duty to provide citizens means of disposing of white and brown goods as a separate waste fraction and set up provisions for collecting this fraction. Producers and importers must notify the environment ministry with details of how collection, transportation and processing of end-of-life equipment is to be organised and funded, with annual reporting of results.

The White and Brown Goods (Disposal) Decree prohibits incineration of this category of waste. The minimum standard for disposal of separately collected appliances is useful application of components, with minimum percentages as laid down in the Decree guidelines. Take-back of WEEE currently stands at 90% (*cf.* table 6 of main report), 73% of which is usefully applied, either intact, as components or as materials. The remaining 27% of scrapped components is incinerated.

Policy on WEEE thus comprises take-back obligations (retailers, municipalities), reuse/recycling targets and a ban on incineration.

Batteries and accumulators
EU Directive 91/157/EC on Spent Batteries and Accumulators sets the terms for Dutch policy on this product group. The scheme for national implementation is shown in table 25.

table 25 Implementation of Directive 91/157/EC in the Netherlands

Batteries (Disposal) Decree	Limits on lead, mercury and cadmium in batteries	Mercury < 0.05% w/w in vehicle batteries Mercury < 0.0005% w/w in small batteries
Regulation establishing additional rules for labelling of batteries and accumulators containing mercury, cadmium or lead		
Regulation on additional rules on a logo for Household Hazardous Waste (HHW)		
National Waste Management Plan (LAP)		

Again, the LAP sectoral plans (nos. 29 and 30) for batteries and accumulators lay down minimum standards for product disposal. For the metals fraction of batteries, useful application is specified. For the various constituents of accumulators (mainly vehicle batteries), useful application is also specified, in the form of materials recycling, with the exception of the bakelite waste arising during processing of old-style accumulators. For plastics components, the minimum standard is also useful application.

In addition, the Waste Substances (Prohibition of Landfill) Decree prohibits the landfilling of separately collected batteries.

Light sources
In the case of lighting waste, the European WEEE Directive (see above, under White and Brown Goods) is elaborated under LAP sectoral plan no. 8. The main items concerned are mercury and sodium vapour lamps (straight and compact) and the fluorescence powder they contain. An 80% target has been set for useful application of all collected waste. Although there is currently probably less than 50% collection, LAP cites a figure of 96% for ‘useful application’ in 2000. Collection of light sources from households is provided for under standing regulations on HHW (sectoral plan no. 17). There is also a ban on landfilling this type of waste.

The LAP sectoral plan comprises a number of regulatory instruments. Under the 1998 Mercury-Containing Products Decree (Environmental Protection Act) mercury-containing fluorescent light sources were banned from sale as of 1 January 2003, with an exception granted for units containing less than 10 or 20 mg of mercury. European Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment, too, restricts the use of mercury, lead and several other substances in light sources, among other things, as of 2007.

The minimum standard of disposal entails full recovery and subsequent processing of mercury, with strict measures to prevent any environmental dispersion. In addition, the glass and metal caps recovered during processing and treatment must be usefully applied in the form of materials recycling. To the extent that it lacks a useful application, the residue left after glass and metal separation and mercury recovery may be disposed of in landfill.

Cable residues

In the case of cable residues, too, the relevant LAP sectoral plan has several regulatory measures. Minimum standards are laid down for the processing and disposal of waste wiring and cabling. For paper- and plastic-insulated cabling and associated fittings the processing ‘hierarchy’ is separation of the metals and residual fraction, followed by materials recycling and incinerator disposal of the residual fraction. In the case of glass-fibre cable residues, the minimum disposal standard is incineration.

L Materials applications

For each of the materials examined in this study, table 26 provides a breakdown of its use in various applications, to the extent we were able to ascertain from the available data. The figures relate to consumption, of relevance for the policy analysis of Chapter 5.

table 26 Applications of principal material flows (% of total flow)

Paper (1)	Total graphic	45%	Aluminium (6)	Construction	22%
	Sanitary	6%		Transport	31%
	Total packaging	47%		Machines	14%
	Others	1%		Other	7%
				Film	9%
Zinc (2)	Zinc plating	43%		Stocks	8%
	Brass	23%		Packaging	8%
	Foundries	13%			
	Semimanufactures	12%			
	Chemicals	8%	Copper (7)	Water pipes	27%
	Other	1%		Electrical cables	48%
Nickel (3)	Stainless steel	66%	Concrete (8)	Civil engineering and utilities construction	70%
	Alloys	11%		Road and water-way engineering	30%
Lead (4)	Batteries	59%	Steel (9)	Construction	32%
	Chemicals	22%		Automotive	7%
	Semimanufactures	16%			
	Cables	2%	Plastics (10)	Automotive	2%
Glass (5)	Packaging	70%	Ceramics		
	Construction	30%	Animal fibres		

Notes:

(1) Based on CEPI (Confederation of European Paper Industries) data, valid for the Netherlands in 2002. Consumption defined as imports + market sales by Dutch industries. Source: CEPI annual statistics, 2002.

(2, 3, 4) Source: Best available Techniques in Non-Ferrous Metals industries. Data are for commercial use.

(5) Source: 3rd Packaging Covenant. Taking the cited figure of 70% for packaging, the remainder was assumed to be for window glazing, i.e. construction.

(6) Source: European Aluminium Association. Statistics based on European sales of the various applications.

(7,8,9) Source: [De Bruyn *et al.*, 2003].

(9,10) Automotive figures calculated by multiplying average quantity of material per vehicle by number of newly registered vehicles in the Netherlands in 2002 and relating this figure to apparent material consumption in 2000.