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Measuring less, knowing more

The use of indicators in dematerialisation policy

Report

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Summary

1 Introduction

A number of studies have reported enthusiastically on the concept of 'dematerialisation', i.e. reducing the amount of materials consumed in an economy while maintaining current or even greater welfare. The argument made is that dematerialisation tackles environmental impacts at their source: less materials use means less environmental burden and less consumption of natural resources.

In the Netherlands, dematerialisation was put on the political agenda in 1999 after tabling of a parliamentary motion to that effect. In the 4th National Environmental Policy Programme (NEPP4) and elsewhere a number of policy questions were subsequently raised, among them the following: what shape might a 'dematerialisation policy' take, and how, i.e. by means of what indicators, might the progress of such policy be monitored? An indicator should provide policy-makers and target groups with information on that progress, both nationally and for individual industrial processes.

This study focuses primarily on the issue of indicators: if a dematerialisation policy were to be implemented, what indicators would be most suitable for monitoring progress?

This question cannot be properly answered without first developing a conception of what an effective dematerialisation policy might look like. As yet there is no such thing, and there are numerous options available, each with their own implications for the choice of indicator(s). Thus, a dematerialisation indicator geared to conserving non-renewable resources will be very different from one designed to help secure climate targets, for example. In the first case recycling may well be an effective strategy towards dematerialisation, but in the second this will hold only if there is a net reduction in CO_2 emissions.

Before dematerialisation can be effectively measured and monitored, more must be known about the designated policy perspective, the kind of indicators to be used and the availability of resource data. In short: measuring less materials requires more knowledge.

2 Scope of the study

Given the fact that no dematerialisation policy yet exists, in developing indicators we set out from scratch. First we examined whether a dematerialisation policy might in principle usefully contribute to wider environmental policy. We conclude that such policy can certainly play a role, provided it meets three criteria:

a It should serve to complement existing environmental policies (impacts policy, energy policy, product policy, etc.).
b It should also have the underlying objective of reducing the environmental burden (associated with materials usage).
c It should focus on materials consumption (rather than inputs) at the national or regional level.

Proceeding from these three policy criteria, we arrived at a basic delimitation of the kind of indicator to be constructed. We then moved on to develop a

set of ten pilot indicators, which were then used to analyse trends in ten key bulk material flows in the Netherlands.
Further assessment of these pilot indicators showed that two were in principle suitable for monitoring the progress of an effective dematerialisation policy (i.e. satisfying the three above criteria). The trend analyses with the pilot indicators demonstrated, moreover, that there may well be a need to initiate some form of dematerialisation policy in the Netherlands.

3 Dematerialisation policy to augment other environmental policy

The NEPP4 document casts dematerialisation mainly in the role of complementary policy, on the grounds that policies geared to curbing specific forms of environmental impact are far more effective, and usually economically sounder, than simply choking off entire flows of material resources. Dematerialisation is thus regarded as an *additional* environmental policy strategy. In this respect there is a useful analogy with energy policy. Dutch energy policy, with concerns extending beyond the environment, seeks to reduce the environment burden associated with energy use by way of four main strategies:

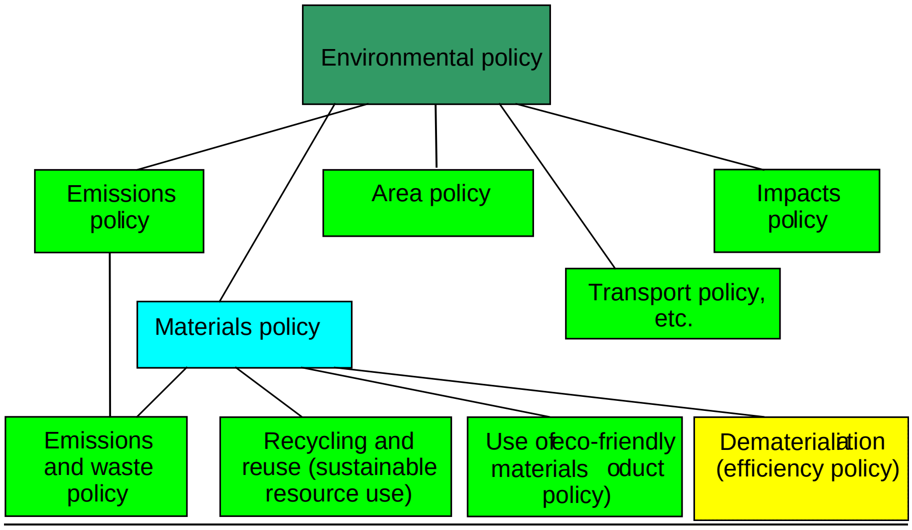
- substitution of fossil fuels for renewable energy sources;
- use of cleaner (e.g. low-carbon) fossil energy sources;
- use of process-integrated and end-of-pipe technologies to reduce emissions;
- improvement of energy efficiency (energy saving).

The aim of a materials policy is to reduce the environmental burden associated with materials consumption. Although Dutch policy in this area is presently less coherent than in the case of energy, the available strategies are similar:

- application of recycling and other forms of reuse, and use of renewable materials (sustainable resource use);
- use of environmentally more benign materials (product policy);
- reduction of material-specific emissions (integrated product management);
- improvement of materials efficiency (dematerialisation).

While the first three of these resource strategies are already embodied fairly consistently in standing policy, a strategy for directly improving the efficiency of resource use is lacking. Although this observation says nothing about the actual need for dematerialisation policy, a complementary role for such policy might be sought in this specific area. The goal of dematerialisation policy would then be to reduce the environmental burden further by improving the efficiency with which materials are used in the economy, or in other words to improve materials productivity.

Figure 1 Role of dematerialisation policy in the wider environmental policy framework



There is some hesitation about instigating policy on dematerialisation, however, and this seems to stem mainly from the fact that the (international) focus to date has been largely on volume materials consumption, expressed in kilograms or tonnes, without attending to the underlying goal of reducing environmental burdens. A policy based simply on kilos, with no reference whatsoever to the kinds of materials or environmental impacts involved could easily lead to a considerable ‘dumbing down’ of environmental policy.

Alternatively, though, there is scope for a *sophisticated* dematerialisation policy in which greater materials efficiency is sought only to the extent that it actually contributes to reducing the materials-related environmental burden.

4 Indicator criteria

Delineating a dematerialisation policy in this fashion has implications for the criteria to be met by the intended indicator. While the traditional dematerialisation literature has focused mainly on reducing aggregate material *inputs* to the national economy (as with the Total Material Requirement (TMR) and Direct Material Input (DMI) indicators), a dematerialisation indicator designed from the perspective of resource efficiency focuses on materials *consumption*, or materials use.

From this angle, a dematerialisation indicator should provide information on materials consumption relative to the utility or income derived from the material flows in question. In addition, the indicator should elucidate whether or not changes in material productivity are environmentally beneficial. After all, there are hundreds of materials and combinations of materials circulating in the Dutch economy and substitution effects may in theory boost materials productivity while also aggravating the net environmental burden. The relationship between environmental gains and materials efficiency is, in other words, far less transparent than in the case of energy. Ideally, a dematerialisation indicator for the environmental policy context should specify how greater materials efficiency translates to environmental gains.

This kind of dematerialisation indicator can be developed at the national, sectoral or company level. In this study it was opted to start by constructing a national indicator, because this is the level to which most of the indicators currently being proposed relate and on which the policy debate centres. At a later stage, indicators might be derived for the industry and company levels, for use in long-term agreements on specific sectoral performance, for example, or in corporate environmental programmes.

For the time being at any rate, it does not appear opportune to include energy-related fossil fuel consumption in an indicator of this kind. Given the magnitude of the flows involved, the contribution of these fuels would simply predominate. Besides, there is already policy in place to boost energy efficiency. In the longer term, though, it might be feasible to merge the two policy fields and monitor them by means of a single indicator.

5 Pilot indicators

In this study we constructed a set of pilot indicators to measure national materials productivity. This exercise had two main objectives: to assess whether the available statistical databases are adequate for constructing a dematerialisation indicator and to examine how material flows might be aggregated to yield a single, consistent indicator.

To this end, data were gathered on the following ten bulk material flows:
1. Naphtha.
2. Steel.
3. Aluminium.
4. Copper.
5. Wood.
6. Paper / Cardboard.
7. Cement.
8. Sand.
9. Chlorine.
10. Soybeans.

For each of these material flows the following statistics were retrieved:
- Production;
- imports;
- exports;
- fraction recycled materials used in production;
- environmental impacts (here: CO_2-equivalents, final waste and land use);
- prices.

Using these data, a set of dematerialisation indicators was constructed with which trends in the selected material flows in the Dutch economy were analysed. One of the main results of this exercise was the insight that the method used for aggregating flows is a critical facet of the indicator. In this project we experimented with aggregation according to mass, statistical weighting and environmental impact.

6 Conclusions and recommendations

A number of conclusions and recommendations follow from this study:

1 Preferred indicators

Based on the results obtained, two indicators were identified as most promising for monitoring the effectiveness of any government policy on dematerialisation:

A An indicator measuring consumption of basic materials, with recycling taken as a form of dematerialisation and material flows statistically weighted (*Indicator 2B, see Figure 7* in chapter 5*).*

B An indicator measuring consumption of basic materials, with both primary and secondary material flows weighted by greenhouse emissions *(Indicator 4A, see Figure 11* in chapter 5*)*.

Among the various pilot indicators developed, these two best satisfy the aforementioned criteria: both provide a sufficiently comprehensive snapshot of (progress on) dematerialisation, understood as improved materials efficiency with probable environmental gains. These indicators still need to be augmented by additional material flows, however. There is also scope for improved assessment of environmental impacts as well as statistical weighting methods, the latter using factor analysis, for example.

Which of the two indicators is eventually chosen depends on the designated goal of dematerialisation policy. If policy-makers wish to weight materials consumption for 'climate impact', the second indicator is the obvious choice. If a different policy focus is adopted, the first is probably more appropriate.

Simple aggregation according to mass, common practice in many studies, was found ultimately to say very little about the environmental burden attributable to material flows.

2 The results of this study call into doubt the wisdom of current European focus on the dematerialisation indicators DMI en TMR

The indicators DMI (Direct Material Input) and TMR (Total Material Requirement), currently the main focus of European policy efforts, are less suitable for monitoring dematerialisation policy, for three main reasons.

First, they measure material *inputs* to the economy. This kind of indicator is unsuitable for pronouncing on the efficiency of materials use, because materials input says little if anything about materials *consumption*. In the specific case of the Netherlands this is doubly important, because here DMI and TMR are both large compared with domestic materials consumption. The prominent role of both basic industries and the transit trade in the Dutch economy means that imports of fossil fuels and minerals are relatively high, although these are largely re-exported in crude or processed form (e.g. naphtha for plastics production, metals).

Second, these indicators aggregate flows according to *mass*, destroying any meaningful correlation with the environmental burden of the individual materials in question. Our study shows that the main upshot is that the indicator is dominated by environmentally irrelevant materials.

Third and last, fossil fuel flows feature relatively prominently in trend analyses using DMI and TMR. To our mind, it is better to address these flows via energy policy rather than materials policy.

3 The sharp rise in materials consumption observed points to the need for a policy on dematerialisation

A second-order conclusion of this study, as revealed in the trend analyses using the pilot indicators, is that dematerialisation policy should indeed be instigated. All the variant indicators examined point to a substantial increase in Dutch materials consumption during the 1990s, with some figures even exceeding GDP growth. In our estimate, economic consumption of the ten major bulk materials selected, analysed 'from cradle to grave', is responsible for about 15% of national emissions of CO_2-equivalents, approximately twice the projection of the government's 4th National Environmental Policy Programme. The growth in materials consumption is proof that this source is not being satisfactorily addressed by standing policy.

In 1997, moreover, the national Office of Economic Policy Analysis (CPB), predicted a major trend towards dematerialisation in the years ahead. It is on these projections that the benchmark *National Environmental Outlook* reports of the National Institute of Public Health and Environmental Protection (RIVM) are based. To date, however, no such trend can be observed. Between 1996 en 2000, particularly, materials consumption in the Netherlands frequently outstripped economic growth, in fact, with precise results depending on which indicator is chosen. Over the decade from 1990 to 2000 the ten dematerialisation indicators increased overall by 24% on average, compared with 33% aggregate economic growth over the same period.

This study indicates that if a dematerialisation policy is indeed implemented, it will have to be fairly sophisticated, not a crude variant based merely on kilograms. Given the results obtained here, this seems well feasible. Additional research will be needed to translate the indicators developed to conversion or efficiency ratios for specific industries, for possible use in long-term agreements on specific sectoral performance, for example, or in corporate environmental programmes.

1 Introduction

1.1 Dematerialisation and sustainable development

The use of material and energy resources is a key expression of the interlinkage between the economy and the natural environment. Ultimately, every form of human environmental impact can be traced back to the use of materials and energy for economic purposes. The flow of resources through the economy has been likened to a society's metabolism. In contrast to the metabolism of natural ecosystems, though, the industrial metabolism of today's economy is not closed: to drive the processes of production and consumption, resources are harvested or mined from nature, to be returned later in the form of carbon dioxide and waste in a near-infinite variety. In this way the economic system places a substantial burden on the ecosystem, and reduction of that burden is now accepted as a key precondition for sustainable development of human society.

One way of approaching this challenge is by 'dematerialising' the economy, i.e. reducing volume flows of material resources and energy in the widest possible sense. This would obviously reduce the rate at which natural resources are being depleted as well as other human impacts on the environment.

There are many illustrative examples of dematerialisation. Motor vehicles and beverage cans, for example, have become steadily lighter over the years. A unit of computer capacity now resides in 16 million times less physical matter than it did in the 1950s. And the ubiquitous e-mail has cut office paper requirements considerably. However, though this report is readily transferable in digital form, for ease of reading you have probably printed out a hard copy. Materials consumption thus always serves a particular function. Staying with the same example, it is questionable whether reading the text from your computer screen would yield any real environmental progress. This requires electrical power, after all, with environmental impacts of its own. If it is to be an end in itself, in other words, dematerialisation must be associated with true environmental progress, however that be measured.

Applying the concept of dematerialisation as an instrument of environmental policy is thus not without its problems. Such problems tend to confuse the discourse on the wisdom and necessity of dematerialisation policy, particularly when it comes to constructing indicators for backing up such policy in quantitative terms. Before considering these issues in more detail though, let us first set out the background and motives for the present study.

1.2 Measuring dematerialisation: motives for this study

The Netherlands' 4th National Environmental Policy Programme (NEPP4) announces the government's intention to develop a national policy on dematerialisation. This move can be traced back to a parliamentary motion tabled in 1999 requesting the government to elaborate a policy on material resources, backed up by due analysis, a set of targets and policy proposals for achieving them. The main motive was an appreciation that, while the volume of raw materials extracted from the earth is declining in the Netherlands, imports of such materials continue to rise, effectively transferring the ecological impacts of Dutch production and consumption to other countries.

At the end of 2001 the Ministry of the Environment (VROM, Climate Change directorate) decreed that research should be undertaken to develop a 'dematerialisation indicator'. A dematerialisation policy of whatever shape will have to be supported by some form of measurement, in order to properly assess dematerialisation trends in the national economy.

This research project was commissioned to CE, which over the past twenty years has gained considerable experience advising government departments on new policy and constructing quantitative policy indicators. In specifying the terms of the project, then, the emphasis came to lie not only on the substantive aspects of an indicator to measure dematerialisation, but also on the facilitative role that CE, and more specifically its business unit CE-Transform, might be able to play in charting the territory for a debate on the wisdom and necessity of government policy on dematerialisation.

To our mind these two aspects – development of a dematerialisation indicator and the need for dematerialisation policy – are intimately related, for the precise policy question that dematerialisation seeks to address will go a long way to determining the nature of the indicator. Thus, an indicator geared to conserving non-renewable resources will be very different from one designed to help secure climate targets, for example. In the first case recycling may well be an effective strategy towards dematerialisation, but in the second this will hold only if there is a net reduction in CO_2 emissions.

1.3 The perspective adopted in this study

The goal of this study is to design one or more useful and practicable dematerialisation indicators for use in government dematerialisation policy.

A dematerialisation indicator assumes the existence of some policy issue. There must be a problem that dematerialisation seeks to address, and before useful indicators can be constructed that problem must first be clearly defined. There are, more specifically, seven key questions to be answered:

1. What problem does dematerialisation seek to address?
2. How is dematerialisation to be dovetailed into the standing policy framework?
3. Should the government actively steer dematerialisation by means of dedicated policy?
4. What criteria must be met by an indicator for which questions (1), (2) and (3) have been answered?
5. For what purpose and at what scale level (micro/macro) is the indicator to be used?
6. What criteria are relevant in opting for one indicator or several?
7. Are there suitable databases available on material resource flows (and environmental impacts) such that indicators can actually be constructed?

As these questions indicate, in this study we have opted to first clarify the basic policy issues before moving on to use this understanding to construct one or more indicators.

There are two pitfalls to avoid in such an approach. In the first place one must beware of fleshing out the policy issues in purely academic fashion. In the scientific literature an enormous amount has been published on dematerialisation and there is already a solid tradition of indicators for making it amenable to measurement. While appreciating the usefulness of many of the yardsticks and insights developed in the literature, though, we are equally aware of serious gaps when it comes to putting these indicators to work in the practical setting of government policy. It is often assumed that 'less is always better'[1]. Perhaps not entirely without justification, Ter Riele *et al.* (2000) conclude that nowhere in Europe is there yet in fact such a thing as 'dematerialisation policy', at either EU or national level[2]. The bridge from science to policy is yet to be built.

The second pitfall to avoid is to take standing policy as the point of departure and simply set to work designing efficient indicators. Although this is the approach most commonly taken in policy studies, it should be noted that there is still no clear-cut conviction on the need for dematerialisation, nor on how dematerialisation should dovetail into the standing policy framework. When it comes to 'dematerialisation policy' even the NEPP4 document itself mentions a variety of motives, users and targets. If there is to be practical development of dematerialisation policy in the Netherlands, however, choices must inevitably be made.

For these reasons – and subsequent to discussions with policy-makers and academics – we devoted the first phase of this study to delineating more precisely the goals that dematerialisation policy might serve. Equipped with the relevant policy documents and with our understanding deepened by discussions with policy-makers on the possible goals and motives of dematerialisation policy, we examined how the policy focus can be rendered more specific and the general implications for development of an indicator.

Subsequently, in the second phase of the project, we investigated the implications of all this for the practical work of indicator construction. To this end we developed a series of pilot indicators in a separate project. These were then evaluated in the light of the motives and practical goals of dematerialisation policy identified in the first phase. These indicators are reported on in the second half of this document.

This study is thus concerned primarily with two issues. In the first place it seeks to develop a perspective on the practicability of dematerialisation policy. Secondly and subsequently, with reference to a series of indicators developed in the course of this study we examine and report on the possible results of such policy if indicators are used for monitoring purposes. Our main interest therefore lies in the general design of indicators as monitoring tools, not in any precise elaboration thereof. Although we have striven to assign quantitative values to the indicators wherever possible, a definitive and robust indicator for dematerialisation will require further elaboration in a follow-up project encompassing a wider set of material resources than that employed here.

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1 The question is essentially whether 'tonnes of raw materials' is an acceptable yardstick for (certain) environmental problems or hopelessly limited. Although it can be scientifically argued that resource tonnage may well be a good measure (see the work of Georgescu-Roegen and Herman Daly, for example, the latter based on the notion of entropy; see chapter 5), the science in question remains controversial. For an interesting review article that also addresses the many criticisms voiced, see Cleveland & Ruth, 1997.

2 Although it may be added that other policy areas frequently have 'hidden' dematerialisation objectives, as in the case of Integrated Product Policy.

1.4 Research plan and report structure

The goal of this study is to construct a series of pilot indicators to serve as a basis for elaborating government policy on dematerialisation. The key issue, of course, is what exactly is to be understood by 'dematerialisation policy'? In chapter 2 we therefore first look at possible definitions of dematerialisation and discuss what form, at a theoretical level, a dematerialisation indicator should take. The main purpose of this theoretical indicator is to enable us to spell out clearly the specific choices to be if dematerialisation is to be monitored using a dedicated indicator.

Next, in chapter 3, we consider the key question of what policy areas might best be served by dematerialisation. As will become clear, the form the indicator takes depends on the designated goal of dematerialisation policy. In this chapter we therefore outline the Dutch policy setting and present a perspective on how dematerialisation might be made to dovetail into the existing environmental policy framework. This has a number of implications for indicator design, which we discuss.

In chapter 4 we present an analysis of the flows of ten major material resources through the Dutch economy and examine the methodological and practical problems encountered in monitoring these flows and their environmental impact.

Trends in these material flows are then assessed using ten different pilot indicators for dematerialisation, developed in chapter 5. Three of these indicators are assessed more closely using sensitivity analysis in chapter 6.

In chapter 7, finally, we present conclusions and recommendations and discuss how the present study relates to other research on dematerialisation.

Following a reference list of literature and other sources consulted, a series of annexes provides a detailed description of the ten material resource flows analysed in this study. An additional annex discusses some alternative perspectives on dematerialisation policy.

Wherever possible, the data used in this report relate to the period 1990-2000. A detailed specification of data and sources is provided in the separate Annexes, which are available in Dutch only. Although these annexes are in Dutch and not part of this English translation, they have been included in the main text for reference.

1.5 Relationship to other studies

The present study can be regarded as a continuation of research already commissioned to other parties by the Dutch environment ministry VROM. We have opted not to reiterate the substance of these studies here, assuming a certain familiarity with the issues on the part of readers and users[3].

Two of the studies of which we assume prior knowledge are particularly important. For English readers we briefly summarise the contents here, with the Dutch title translated:

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[3] As a consequence, concepts like Direct Material Input (DMI), Total Material Requirement (TMR), Ecological Footprint and entropy are explained here in a single sentence, with no reference to the background literature or considerations reported therein.

'De Ontkoppelingsindicator (The decoupling-indicator)' (Huele *et al.*, 1999)
This study provides a useful survey of the indicators currently in use for measuring delinking in general and dematerialisation in particular. The various options for aggregating material flows are examined, including weighting by mass and environmental impact, expert panels and statistical weighting (principal component analysis). This survey discusses the full range of yardsticks developed in the literature (DMI, TRM, green GDP, Ecological Footprint, etc.). Those with no prior knowledge of these concepts are advised to read this document.

This study, in Dutch, can be downloaded from:
www.leidenuniv.nl/cml/ssp/publications/wp99006.pdf

'Dematerialisation: less clear than it seems' (ter Riele *et al.,* 2000)
This study examines various definitions of dematerialisation, identifying different schools of thought, and discusses European efforts towards dematerialisation as well as worldwide research on the topic.

This study can be downloaded from:
http://www.vhk.nl/download/Dematerialisation.pdf

In parallel with the present study, VROM has also commissioned to Delft Technological University a study on the *administrative* aspects of dematerialisation policy, comprising a policy analysis of dematerialisation and the various players on the dematerialisation stage.

2 Dematerialisation and indicators to measure it

In this chapter we consider the basic choices to be made prior to constructing an indicator for dematerialisation. We do so by looking at a simple model of an indicator that can be seen as representative for any yardstick seeking to measure dematerialisation. First of all, though, let us consider how the concept is to be defined.

2.1 Defining the concept

There are a great many definitions of dematerialisation. Consider the following two:

1 According to the Netherlands' Fourth National Environmental Policy Plan (NEPP4), dematerialisation is: *"the reduction of material flows per unit output of goods and services provided, with a view to reducing natural resource depletion and environmental impact"* (NMP4, p. 126).

2 Stichting Natuur en Milieu, a prominent Dutch environmental organisation, employs the following definition: *"Dematerialisation is a strategy aimed at reducing energy and material inputs to an economic system or activity, such that the environmental impact of that system or activity is reduced"* (Blonk, 2002).

These two definitions immediately signal three key aspects of what dematerialisation is to measure:
- Should it measure flows of materials only, or energy flows too?
- Should it measure reductions in absolute terms, or relate them to aggregate output of goods and services (or Gross domestic Product)?
- Should it measure resource depletion, environmental impact, or both?

These are by no means the only choices to be made, in fact, and we shall now explore these further by considering a simple model of a dematerialisation indicator.

2.2 Constructing a simple indicator

Pursuing the definition provided in NEPP4, a dematerialisation indicator might be defined as follows:

An indicator, i.e. numerical parameter, reflecting changes in the sum total of material flows over time as a function of the utility derived from those flows.

The aggregation of flows is important here. This is common practice, to avoid the term 'dematerialisation' being used to cover substitution of one resource flow for another. At the same, though, it is not absolutely essential.

In schematic form, then, a dematerialisation indicator will have the following form:

$$Demat \quad indicator = \frac{\Sigma M_i \bullet W_i}{f(Y)}$$

with the symbols as follows:

1 Subscript i (= *1….n*) represents the *n* materials included in the indicator.
2 M_i represents the flow of each material *i* included in the indicator, measured as mass (kilograms). Where precisely in the supply chain this flow is measured is crucially important, as we shall see below in section 2.2.2.
3 W_i is the relative weight attached to each of the constituent flows M_i in the overall indicator for dematerialisation. Thus, $W_i=1$ (for all *i*) means that all flows are accorded equal weight and thus summed purely on the basis of mass.
4 f(Y) represents the utility deriving from the material flows. Although this is usually expressed as Gross Domestic Product (GDP), there are alternatives.

With this definition, we have in fact identified four key preliminary choices to be made before embarking on construction of a dematerialisation indicator:

1 Which material flows are to be monitored?
2 How are they are to be measured?
3 How are they are to be weighted?
4 How is their utility to be measured?

Let us then examine these issues one by one.

2.2.1 Selecting materials for inclusion

In environmentally oriented economic analysis the following five categories of resources are commonly distinguished (cf. Reijnders, 1999; Muilerman & Blonk, 2001)[4]:

1 *Flow resources* such as wind and solar insolation, use of which does not lead to a reduction of quality or volume.
2 *Renewable biotic resources* such as wood, crops and animal products that can be harvested indefinitely as long as consumption does not exceed growth (natural or assisted).
3 *Renewable abiotic resources* such as land and water, use of which leads to a loss of quality of the available stock, but which are regenerated in the medium to longer term (20 - 70 years).
4 *Non-renewable abiotic energy resources* such as fossil fuels, which are regenerated only very slowly and which cannot be recycled.
5 *Non-renewable abiotic non-energy resources* such as metals, which are likewise regenerated very slowly but which can be recycled.

While the first category of resources is included in few studies, all the others feature consistently in work on indicators seeking to measure dematerialisation of the economy. Given the stark image of their ‘finite limits', it was the non-renewable abiotic resources that used to be the traditional area of concern (as first voiced by the Club van Rome: Meadows *et al.*, 1972). Thirty years on, though, it has become clear that it is overconsumption of *renewable* biotic and abiotic resources, above all, that is threatening planetary sustainability. Today it is deforestation, overfishing and soil erosion that form

[4] To which a sixth category might perhaps be added: non-renewable biotic resources, taken as standing for biodiversity. Although biodiversity is an important environmental theme, it is not entirely clear whether (and how) it might be incorporated in an indicator for dematerialisation. Animal products (fish, etc.) are already included in the second category above.

the most pressing environmental problems associated with natural resource stocks.

Obviously, the choice of material resources to be included in the indicator will depend on practical considerations like data availability as well as the envisaged goals of a 'dematerialisation policy'. After all, the respective categories of resources are implicated in a wide range of problems affecting the natural environment, and thus human society, as summarised in Table 1.

Table 1 Principal environmental problems associated with resource flows[5]

Resource flow	**Principal environmental problems**
Renewable biotic resources (wood, fish, etc.)	Harvests above regeneration capacity Declining biodiversity
Renewable abiotic resources (water, soil)	Resource scarcity Landscape deterioration Land use Declining biodiversity
Non-renewable abiotic energy resources	Climate change Acidification Resource scarcity (depletion)
Non-renewable abiotic non-energy resources	Acidification Waste Toxicity Resource depletion

2.2.2 Setting system boundaries

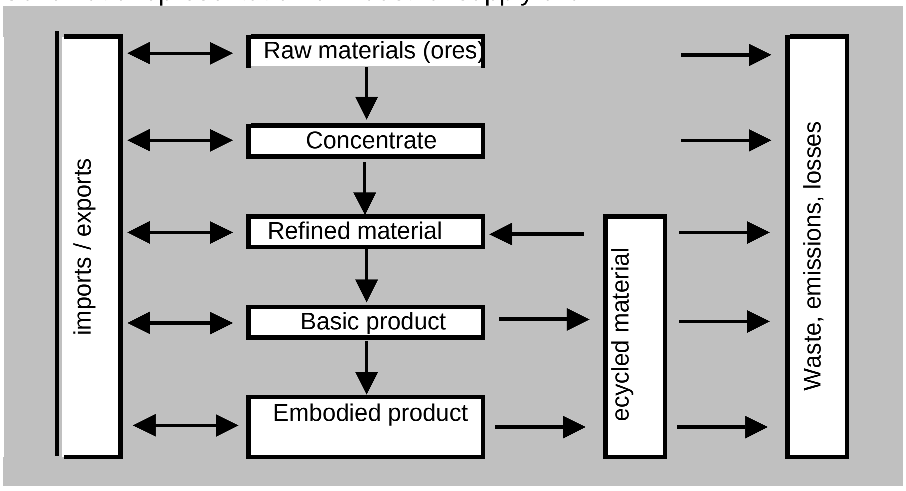
Just as important as the choice of resources to be included in the indicator is the issue of how and where to measure their flows. There are four decisions to be made here:

1 At what point in the respective supply chain is the flow to be measured?
2 Should the focus be on resource production or consumption?
3 Should 'hidden flows' be included, i.e. materials used in resource extraction and refinement?
4 How are recycled materials to be treated?

In every industrial supply chain, materials are worked up from crude to processed form and ultimately to a variety of end products. Resource imports may consequently take any of these forms. Copper, for example, may be imported as copper ore, refined copper, recycled copper, copper wire or wiring installed in vehicles, kitchen appliances, televisions and so on. The various steps are shown in Figure 2. The question now is *which* flow of materials is the dematerialisation indicator to be based on: the copper ore, the refined metal, or the copper wiring in products and appliances?

[5] This table is not intended to be exhaustive. It may also be queried whether scarcity and depletion are an environmental problem or merely an economic one. As argued in Annex C, it is our view that scarcity of non-renewable resources should be seen as a purely economic problem .

Figure 2 Schematic representation of industrial supply chain



A related but more fundamental choice is whether the dematerialisation indicator should relate to (national) consumption or production. Depending on the resource in question, there are enormous differences in the number and kind of links in the chain that take place in the Netherlands. In the case of copper the first three links are not represented domestically and the basic product, wire rod, is imported mainly from Belgium. The Dutch end product, copper wiring, is exported again, to be subsequently re-imported as wiring embodied in cars and other consumer products. In the case of steel, to take another example, it is iron ore that is imported to the Netherlands and steel plates for cars, for example, that is exported.

The third important issue is that recovery of mineral ores and fossil fuels, in particular, is accompanied by numerous 'hidden' resource flows, in the form of mining and industrial wastes left behind in the origin country[6]. One of the questions is whether or not these 'rucksacks' are also to be taken as part of the resource flow.

The final issue is how recycled materials are to be addressed. Are they 'positive' material flows, resulting in materialisation or 'negative' flows, resulting in dematerialisation?

One of the factors governing decisions on these four aspects of delineation will be data availability. While an idealist will argue for monitoring the *entire* supply chain (i.e. including all the materials ultimately embodied in the product), in practice this is an impossible task. The enormous diversity of products and composite materials circulating in the economy and the continual emergence of new products and disappearance of others makes monitoring at this level of detail simply unfeasible.

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6 This is sometimes referred to as the 'ecological rucksack' and is an essential element in any analysis of the Total Material Requirement (TMR) of a country.

In practice, then, flow measurement will generally be at the level of the basic material product; i.e. copper, sand, cement[7]. An analysis at that level, however, makes the choice as to whether the dematerialisation indicator should be based on production or consumption an important one. A country with a proliferation of basic industries like the Netherlands will generally score higher on a yardstick based on production, while a country producing mainly consumer products and machinery like Japan will score higher on a consumption-based measure. All of this need not necessarily tell us anything about the actual burden the final consumption of the respective countries places on natural resources and the environment.

Before useful choices can be made on these four aspects of resource flow delimitation, the specific focus and goals of dematerialisation policy must first be formulated more clearly. If resource depletion is the principal policy objective, for example, recycling can usefully be included in the indicator.

2.2.3 Weighting the flows

Once decisions have been made regarding the materials to be included in the indicator and how their flows are to be measured, the next step is to decide how the flows are to be aggregated. For this purpose some form of weighting procedure is required.

In general terms the following options are available for aggregation:

1 By mass (kg), i.e. W_i equals 1 (for all *i*).
2 By volume (m^3), as described by Moll (1993) and others.
3 Using statistical methods, as described by Cleveland & Ruth (1999) and Huele *et al.* (1999).
4 By environmental impact, measured in terms of CO_2 emissions, biodiversity, toxicity, land use, acidification and so on[8].
5 Using shadow prices, as proposed by CE (1996).
6 By expert panel, e.g. the NOGEPA weighting factors (Huppes *et al.*, 1997).
7 Other methods, e.g. based on resource depletion levels.

Of these methods it is only the first two, weighting by mass and by volume, that are relatively free of controversy. To a greater or lesser extent, all the others necessitate assumptions. In the last four methods, moreover, the weighting factors vary over time as the environmental burden of the supply chain chops and changes.

It is again clear that a key issue affecting the choice of weighting factor is the intended aim of the dematerialisation indicator. If the main aim is to help reduce the overall environmental burden of resource use, the obvious choice is to weight the constituent flows according to their respective environmental impact.

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[7] It has been estimated by the Wupperthal Institute that there are only about 100 abiotic resource flows of any great magnitude in western economies. In constructing a dematerialisation indicator, though, it is questionable whether volume should be an over-riding factor. This is the issue of weighting, which we shall be discussing below.

[8] A key issue here is which environmental impacts are to be included: just those occurring at the locus of flow measurement, or all the way down the supply chain, 'from the cradle to the grave'. We take up this discussion again in chapter 4.

2.2.4 Measuring flow utility

Eventually, the weighted flows must be summed to yield the numerator of the dematerialisation indicator. The denominator is *f(Y)*, the function, or utility, of the flows in question. Thus, at the product level, the unit function served by a refrigerator, for example, might be expressed as the cooling of one kilogram of food.

If the indicator is to be used at the national level, Gross domestic Product is generally taken as *f(Y)*. An alternative is to set *f*(Y) equal to 1, thus simply monitoring the material flows themselves rather than their relationship to GDP.

2.3 Conclusions

Before a dematerialisation indicator can be constructed a number of preliminary choices must first be made. Principal among these, to our mind, are the following:

1. Choice of resources: which resource flows are to be included in the indicator? Is energy to be included or not?
2. Is the focus to be on production or consumption of materials, and at what point in the supply chain are flows to be measured? Are back-end environmental impacts to be included, and how is recycling to be addressed?
3. Weighting: how are flows to be weighted relative to one another?

Before choices can effectively be made on any of these issues, though, there must first be a conception of what dematerialisation policy is aiming to achieve. It is to this central issue that we now turn in chapter 3.

3 Dematerialisation policy

In this chapter we examine how policy-makers pursuing dematerialisation have responded to the basic design choices identified in the previous chapter. To this end, in section 3.1 we first consider how dematerialisation came onto the policy agenda, proceeding in sections 3.2 en 3.3 to analyse the aims, users and perspectives specifically cited in the Netherlands' Fourth National Environmental Policy Plan (NEPP4) in connection with the topic. We then outline a perspective on dematerialisation policy we feel is in line with the apparent intentions of NEPP4. This vision provides a framework with which to construct the pilot indicators in later chapters.

In the realisation that the perspective adopted here is just one among many, in the Annex C of the Dutch study we have reviewed a number of other possible motives for implementing a policy on dematerialisation which have not been selected during the course of this study.

3.1 Dematerialisation: a brief history

The concept of 'dematerialisation' was first cited in the scientific literature on natural resources and resource scarcity. In that literature dematerialisation has often been approached as a purely descriptive phenomenon, to describe the absolute or relative decline (as a function of GDP) in selected resources over time. Originally studied by mining economists in order to predict demand for key resources (see e.g. Malenbaum, 1978; Tilton, 1986), in the late 1980s the concept began to draw the interest of researchers in search of a broad proxy for environment impact more generally (Jänicke *et al.*, 1989)[9]. Dematerialisation was held to be "a sign of hope" (von Weiszacker & Schmidt-Bleek, 1994).

One consequence of 'dematerialising' the economy is greater added value per unit input of material resources. Over the longer term this process of rising resource productivity can be observed with a great many resources[10]. The main driving forces are generally held to be technological advance and the economic incentive for efficient use of resources, as cost items in the production of goods and services.

It has also been noted, however, that this historical process of 'dematerialisation' is in reality mainly *resource substitution* or transmaterialisation[11]. Because production statistics on resource consumption are generally confined to older, 'traditional' materials (thus often ignoring polymers and composites, for example), some authors charge that dematerialisation analysis is concerned mainly with materials that have already been substituted, for reasons of process efficiency or more stringent product specifications. Others, like De Bruyn & Opschoor (1997), for example, have concluded that there is more likely to have been *rematerialisation* since the slump in world resource prices that occurred in the early 80s.

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9 Most of this interest in a proxy for environmental impact was practically motivated, it may be added: in the late '80s there were no consistent time series available for such impact.

10 See e.g. Williams, Larson & Ross (1987).

11 See Labys & Wadell (1989).

In the late 90s scientists and politicians began to interpret dematerialisation normatively, as a yardstick measuring progress towards sustainable development. The ‘Factor 10’ and ‘Factor 4’ initiatives are emblematic here. The second of these is based on an analogy with climate policy. Assuming the need for a 50% reduction in greenhouse gas emissions over the next 50 years and a doubling of current emissions due to autonomous growth, emissions must be reduced by a factor 4 over that period to achieve the target set. For the sake of ease, it is then assumed that CO_2 emissions and material input are linked one to one.

The Factor 4 literature contains many attractive examples of dematerialisation at the product level. For politicians these may well have served as a source of inspiration in getting dematerialisation on the political agenda. It is to the resultant policy initiatives that we turn in the following section.

3.2 Dematerialisation policy in the Netherlands and Europe

In the Netherlands dematerialisation policy was fist introduced in the Fourth National Environmental Policy Programme, already cited. It is useful here to examine precisely what is understood by dematerialisation policy in this document. There is in fact little mention of the motives for establishing a national policy on dematerialisation, a term first cited in a chapter on transition management (p. 102), where implementation of a monitoring system is announced to track resource depletion rates and trends in CO_2 emissions, among other parameters. The suggestion would seem to be that concerns about resource depletion and climate change form the prime motives for instigating a dematerialisation policy.

Although dematerialisation also obviously influences environmental quality on other ways, NEPP4 (p. 126) states that: “existing policies for reducing the environmental burden are often more effective, in terms of outcome as well as cost. At-source measures in production processes, for example, generally lead to far greater improvements than dematerialisation. [….] Dematerialisation serves mainly to complement existing policies. The standing policy framework already provides an incentive to reduce resource consumption, in tandem with reduced energy consumption. The main contribution of dematerialisation policy is therefore to focus attention on the use of energy and materials and develop and implement additional policies to address that use".

This sets limits on the role of dematerialisation in Dutch environmental policy: above all that role is to be *complementary*, serving to implement additional policies to reduce the overall environmental burden of the Dutch economy.

In implementing a dematerialisation policy, NEPP4 (p. 143 *et seq.*) sees an important role for both producers and consumers. "Dematerialisation shall play a more prominent part in the scala of policy tools employed, with specific modules being developed for reducing resource consumption. One such instrument shall be Life Cycle Assessment […]. There must also be clarity about the environmental gains to be achieved through dematerialisation. This is of concern not only to producers, i.e. business and industry, but also to consumers, for only then will there be sufficient motivation for all parties to contribute. Steps will also have to be taken to ensure that dedicated know-how is made available to retailers, so they can continue to improve the sustainability of their product assortment."

As the basic foundation for a national dematerialisation policy NEPP4 sees a monitoring system, yet to be developed, which (p. 142):
"…accounts for resource depletion levels and energy consumption. Among the aims are to:
- to monitor changes in resource consumption, ecosystems and the economy that lead to sustainable patterns of consumption;
- to analyse the factors determining demand for materials and energy;
- to establish the environmental burden of resource flows and energy consumption and thus also the potential environmental gains to be achieved (the linkage with CO_2 emissions is particularly important here)."

Trends are to be tracked by means of a dematerialisation indicator which, for individual firms and industries as well as for the Netherlands as a whole, should provide an indication of the progress made on dematerialisation. "Development of a dematerialisation indicator shall be based on indicators for fossil fuels, wood, food, water, plastics, construction materials and metals. There may also be a role for derived indicators relating to wastes. In developing a dematerialisation indicator, the Netherlands shall link up as far as possible with European efforts to develop this kind of policy tool."

Once developed, dematerialisation policy is to be implemented with the aim of reducing the environmental impact of resource use. In the conception of NEPP4 dematerialisation policy is intended above all to support climate policy, product policy and waste policy, as well as policy to reduce natural resource depletion.

Plans for dematerialisation policy are also being developed at the European level. The EU's 6th Environmental Action Programme has a section on dematerialisation, stating an intention to develop some form of dematerialisation policy to address the issue of resource depletion. Although this is not elaborated further in the 6th Action Programme, the European Commission is presently examining how such policy might be fleshed out. Important in this context are ongoing discussions in Germany, Austria and the United Kingdom, in particular, on the importance of reducing materials usage.

3.3 Dematerialisation as complementary policy

In broad terms, NEPP4 is clear about the envisaged role of dematerialisation in Dutch environmental policy: it is seen above all as complementary to standing policies. In other words it must have something to add. As stated, NEPP4 cites product policy, climate policy, waste policy and policy to address resource depletion as the main fields in which such complementary policy is necessary.

There is less clarity, however, about how that complementary role is to be delineated. After all, policies geared to reducing resource use will have wide and varied implications for other areas of environmental policy and may well even lead to conflicts. At the individual product level there are many examples of such conflicts. Thus, while a beverage carton may in itself be environmentally preferable to a one-way, disposable plastic bottle, the former is heavier. The same holds for a returnable bottle with deposit. Simply striving for dematerialisation at any price may therefore lead to undesired forms of resource substitution that frustrate current product and waste policies.

These kinds of conflicts can arise at the national level, too. Dematerialisation may go hand in hand with materials substitution with a net negative environmental impact. A more precise delineation of dematerialisation within the environmental policy setting may then be useful, because this will help define the scope of the intended dematerialisation policy.

In discussions with the Dutch Ministry of the Environment (VROM) and others we have attempted to establish a clear and transparent framework for dematerialisation policy. The basic point of departure here was that such policy should, first, complement standing policies and, second, tackle an environmental problem unsatisfactorily covered by those policies at present.

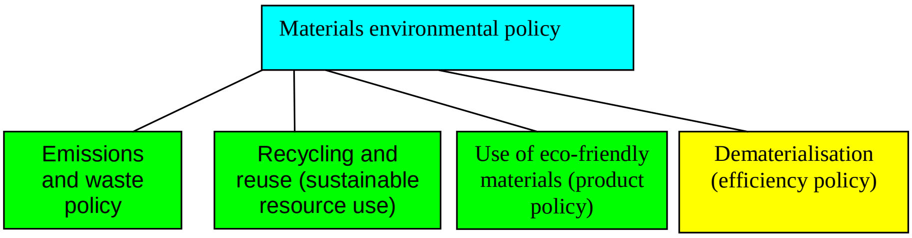
During those talks analogies with energy policy were drawn, all parties holding that energy policy has been reasonably consistent to date and that there are lessons to be learned here for dematerialisation policy.

Dutch energy policy seeks to reduce the environment burden associated with energy use by way of four main strategies (as set out, for example, in the government's 3rd White Paper on Energy and in NEPP4, p. 86 *et seq.*):
– greater use of sustainable energy sources;
– and use of clean technologies to minimise emissions;
– use of cleaner (e.g. low-carbon) fossil energy sources;
– improvement of energy efficiency (energy saving).

To our mind, materials policy is also part of environmental policy, the aim being to reduce the overall environmental burden associated with materials use. Although Dutch policy in this area is presently less coherent than in the case of energy, the available strategies are similar:
– application of recycling and use of renewable (sustainable resource use);
– reduction of material-specific emissions (integrated product management);
– use of environmentally more benign materials (substitution policy);
– improvement of materials efficiency (dematerialisation).

While the first three of these resource strategies are already embodied fairly consistently in standing policy, a strategy for directly improving the efficiency of materials use is lacking. In our view, dematerialisation can fulfil precisely this role. From this perspective, then, dematerialisation policy is analogous to policy to boost energy efficiency. The motive for instigating a dematerialisation policy is thus to have a supplementary strategy on material resources with which to further reduce the overall environmental burden associated with the Dutch economy. This does not mean that dematerialisation is always good for the environment. Just as with energy efficiency, owing to feedback loops and use of environmentally harmful substitute materials, dematerialisation does not inevitably reduce the environmental burden. Although the underlying reasoning is that improved resource efficiency will, by and large, reduce environmental impact, just as greater energy efficiency will generally reduce environmental burdens, it should be seen as a rule of thumb rather than a fixed law.

Figure 3 Four resource policy strategies



This perspective – dematerialisation policy as an element of policy to improve the efficiency of material resource use – satisfies the two principal conditions established above: that such policy should complement the current policy toolkit in areas not presently covered. In principle, then, the concept of dematerialisation is amenable to translation to policy terms. Analogous to energy policy, where the government's aim is to achieve efficiency savings of 33% between 1995 and 2020 (as per the 3rd White Paper on Energy), targets could be set for improving materials productivity[12]. To pursue this goal, though, it is necessary that dematerialisation be appropriately measured.

3.4 Constructing an indicator

Now we have delineated in more detail what we mean by dematerialisation policy, let us examine the possible consequences for the design of an indicator to measure it. The first task is to decide on which level the indicator is to focus. In principle there are two strategies available: the indicator can start out from micro-level data, using Life Cycle Assessments for example, with results subsequently being aggregated to a national figure; alternatively, it can be based on macro-economic flows, with results subsequently being broken down for target groups at the micro-level.

Although NEPP4 is not unequivocal on this point, there appears to be a preference for a macro-indicator, i.e. for the Dutch economy as a whole, which can then be put to work in policies at the micro-level. This impression is reinforced by the statement that Dutch policy should tie in with European developments, where resource flows are now being analysed more and more at the national level (cf. the work of the Wupperthal Institute and of IFF in Austria) with less focus on LCAs on individual products, which are now used merely as case studies in describing macro-level resource flows[13].

At this stage, therefore, we opt to develop a macro-indicator and thus to establish the materials efficiency of the Dutch economy as a whole. This would provide a tool for monitoring the effectiveness of a national-level policy on dematerialisation.

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12 We thereby assume that materials productivity is the reciprocal of dematerialisation, taken as resource efficiency, as is generally done in the literature; see e.g. De Bruyn & Opschoor (1997).

13 National targets have the added benefit of providing a reference point for market (i.e. business and consumer) initiatives. The business community has already implemented a variety of 'eco-efficiency' initiatives, into which dematerialisation could dovetail nicely. One problem, however, is that these initiatives are hard to aggregate at the national (or even regional) level (see e.g. Hertwich, 1997). This diminishes transparency, preventing scientists and politicians from assessing the extent to which such action is leading to true environmental improvement. The lack of democratic checks and balances is a second, allied objection.

Before this kind of national indicator can be elaborated, however, there are still a number of choices to be made, as argued in chapter 2. The most important of these concern:

- Choice of resources: which material flows is the indicator to encompass?
- Measurement: how and at what point in the supply chain are these flows to be measured? Are environmental impacts at the back end of the chain to be included, and how is recycling to be addressed?
- Weighting: how are these flows to be weighted relative to one another?

These are the issues we discuss in the next section. In doing so, we first turn to energy and, in particular, how energy efficiency at the level of individual firms can be translated to a figure for national efficiency. We then consider the implications for dematerialisation.

3.4.1 Energy efficiency and conversion efficiency

In energy policy a distinction is made between the energy efficiencies of equipment, production processes and the national economy.

To calculate the energy efficiency of a given item of plant or equipment is relatively straightforward: one simply compares the energy input in joules with the energy functions supplied as output. As inputs and outputs can both be expressed in energy terms, a simple ratio is generally obtained for the *energy conversion efficiency* for the plant or process concerned. Thus, a Gas Turbine Combined Cycle generating plant today has an electrical conversion efficiency of about 55%, while high-efficiency boilers have a thermal efficiency of around 90%. For these and similar efficiencies there are currently government standards in force.

For many enterprises the input-output ratio is not that clear, however, because the output is ‘products sold’. Here the government has set long-term efficiency targets for individual industries and products. Thus, there are different energy standards in force for producing a kilo of cheese or steel plating. Still, these can be also viewed as conversion efficiencies, for they express the amount of energy required to create a physical end product:

$$Energy \quad efficiency = \frac{energy \quad input(gJ)}{product}$$

This sectoral approach is driven by the framework policy laid down in the 3rd White Paper on Energy, cited earlier, which sets the objective of boosting national energy efficiency by 33% over a period of 25 years, an improvement of around 1.1% per annum. One problem with conversion ratios keyed to specific processes, however, is that they cannot be aggregated to yield an energy efficiency figure at the national level. While the numerator, energy input, is the same for all conversion efficiency ratios, the denominator is not, standing as it does for a multitude of products. One way the figures can still be aggregated is to express the products in terms of their *value*, in other words in monetary terms. The total value of all the goods and services produced in the Netherlands is precisely the Gross Domestic Product, GDP. Defining ‘energy intensity’ as national energy consumption divided by GDP, we then have a yardstick for energy efficiency at the national level. This energy intensity can also be viewed as ‘energy productivity’: the amount of income generated with a given amount of energy.

One indicator that is frequently used in this context is the Total Primary Energy Supply (TPES), defined as follows:

$$TPES = \sum_{i=1}^{k} P_i + \sum_{i=1}^{n} (I_i - E_i - B_i \pm Z_i)$$

where:
i = an energy resource,
k = number of primary energy resources (coal, oil, gas, etc.),
P_i = production of primary energy resource i,
n = number of energy resources, including derived sources like electricity, use of which is converted back to primary sources,
I_i = imports of energy resource i,
E_i = exports of energy resource i,
B_i = use of energy resource i by international shipping[14],
Z_i = change in stock of energy resource i.

The TPES represents the total quantity of primary energy resources consumed by a given economy. It is a consumption-based indicator, because energy imports and exports are added to or deducted from production. The ratio between TPES and GDP is the energy intensity, an indicator for the average efficiency with which a country uses energy to generate income. In the literature TPES/GDP ratios are often used to compare national energy efficiencies (see e.g. Nilsson, 1993).

3.4.2 A dematerialisation indicator, and where to measure it

If we now attempt to develop a similar yardstick for dematerialisation a number of problems are encountered. Although it may often be possible to establish 'conversion efficiencies' at the sectoral and/or company level, these will be different for every link in the supply chain illustrated in Figure 1 above. For a copper smelter, for example, it will be the ratio between the input of copper ore and ancillary materials and the output of refined copper, while for a producer of electrical wire it will be the volume ratio between copper rod and wire output.

What is apparent here is that it is not only the denominator but also the numerator of these ratios that differs: in the first case we are concerned with copper ore and in the second with copper rod.

This need not be problematical for constructing a dematerialisation indicator, however, provided one aggregates the two flows in terms of kilogram mass and regards this as a meaningful indicator for the environmental burden associated with the flows in question. Problems arise, though, because for the first four steps distinguished in Figure 1, import and export flows must also be included[15]. To arrive at a comparable measure for primary resource requirements, moreover, all the import and export flows embodied in downstream links in the chain must be converted back to inputs of primary resources to the economy, in other words to mineral ores and other unprocessed resources, and all recycled resources must not be taken into account.

[14] It is thereby generally assumed that all the fuel oil burned by marine shipping is to be ascribed to foreign vessels.

[15] The last step in the chain, final products, is not distinguished in the TPES energy yardstick either and can therefore be omitted here.

Even for a material like zinc this would be an extremely difficult task involving innumerable calculations. For a set of 40 to 50 materials it would simply be impossible.

Raw materials consumption, which stand for the very first link in the material chain and thus for mineral ores and other unprocessed resources, may therefore not be a promising candidate for a dematerialisation indicator. An alternative route is to consider the level of ‘basic’ products or materials, encompassing both primary materials and semi-manufactures, viz. cement, paper, phosphate, agricultural produce and in the case of steel, for example, plating, slabs, pipes and tubing and so on. This may provide us with a meaningful proxy for the material requirements of a national economy. This Total Basic Material Supply (TBMS) might be defined as:

$$TBMS = \sum_{i=1}^{n} P_i + (I_i - E_i \pm Z_i)$$

where:
i = a basic material,
n = number of materials included in the indicator,
P_i= production of material i,
I_i= imports of material i,
E_i = exports of material i,
Z_i = deductions from and additions to stock of material i.

Because data on materials stockpiling and withdrawal are difficult to establish, the last term is generally omitted and the formula shortened to express the ‘apparent consumption’ of material i, that is, production plus imports minus exports.

A few remarks are in order here:
1 The principal reason for here restricting the analysis of material flows to a single step, that of ‘basic products’, is to enable development of an indicator for dematerialisation that is practicable to calculate.
2 In principle, an indicator like TBMS could just as well be measured at a different level, for example that of raw materials. Aggregate consumption at this level is very different from the total consumption of what we have here termed basic materials. ‘Raw material consumption’ will primarily focus on the materials productivity of the basic industry, ‘basic material consumption’ on that of the consumer products and machine-building industries.
3 Which level is ultimately opted for will be determined in part by the anticipated environmental gains of dematerialisation in the various echelons of supply. We anticipate, *a priori*, that these gains will be greatest in the consumer products and machine-building industries, because this is precisely where there is greatest scope for materials substitution as well as efficiency improvement: products can be manufactured using all kinds of materials, each with their own environmental profile. Upstream in the basic metals industry such substitution is scarcely feasible, if at all.
4 At the present stage of development, the upstream links associated with basic materials production have not been incorporated in the dematerialisation indicator. This means that imports, production and exports of mineral ores and other raw materials are not counted as domestic consumption. This procedure appears to be in order, since these materials do not *themselves* drive consumption: they merely serve to produce the basic materials. This is not to deny, though, that there may well be potential for dematerialisation in such basic industries and future research

might examine whether it is desirable to incorporate this potential in a dematerialisation indicator.

3.4.3 Choice of materials for inclusion

NEPP4 cites a number of rough categories of resources that should be included in the indicator, viz. fossil fuels, wood, foodstuffs, water, plastics, construction materials and metals. This indeed covers the full spectrum of potentially environmentally harmful material flows. However, a truly comprehensive analysis of all materials and combinations of materials circulating in the Dutch economy is to all practical intents impossible because data collection would be just too time-consuming.

In selecting a subset of materials to include in the indicator the key thing is therefore to the materials deemed to be most environmentally harmful. Although analyses of the environmental impacts of virtually all materials are to be found in the LCA literature, the information is often incomplete. The Centre of Environmental Science (CML) of Leiden University is currently engaged in parallel research to quantify more precisely the relative environmental burden of the principal material resources so that this information can be used in ultimate construction of one or more indicators.

The choice of materials to be included is also determined by the 'complementary' role assigned to dematerialisation policy, defined as policy to improve the efficiency of resource use within the environmental policy setting. Given the energy policies already in place, it would seem inappropriate to include fossil fuels in a dematerialisation indicator. An exception will have to be made, though, for the use of fossil resources to produce materials like plastics that are not covered by standing agreements on energy efficiency.

In chapters 4 and 5 we shall select ten key bulk materials for inclusion in a pilot dematerialisation indicator. At a later stage, this set of materials can then be amended and extended using the CML research results to arrive at a more complete policy indicator with which to monitor the environmentally relevant dematerialisation of the Dutch economy.

3.4.4 Weighting the flows

If dematerialisation is approached merely as improved materials efficiency it may well have unwanted environmental impacts. To guard against these kind of effects it is useful to *weight* the constituent material flows included in the indicator according to their environmental impact.

The decision whether or not to weight flows in this way depends partly on the role dematerialisation is to play in environmental policy. If it is seen purely as an element of efficiency policy, purists might reject weighting as unnecessary. After all, reducing the environmental impact of resource use is in principle already covered by policies in other areas.

It can be argued, on the other hand, that in itself there is not much point in reducing product weight if this not accompanied by concrete environmental gains. This is truer for material resources than for energy. While reducing the energy content of a product is virtually always environmentally beneficial, this is far less the case for weight reduction.

To gain a better understanding of the importance of weighting in arriving at an aggregate indicator for dematerialisation, in the following chapters we develop both unweighted variants and variants with material flows weighted for environmental impact. As we shall argue in chapter 4, this impact will be 'from cradle to grave'.

3.5 Conclusions

From this review of earlier efforts on dematerialisation policy and indicators a number of conclusions can be drawn:

- NEPP4 casts dematerialisation mainly in the role of complementary policy; policies geared to curbing specific forms of environmental impact are far more effective than simply choking off the material flow.
- Elaborating dematerialisation policy as an element of resource policy, with the aim of improving the efficiency of resource use in the national economy, appears to adequately complement current policies and to be a desirable move because such policy still lacks sufficient coherence.
- This means that the main materials included in a dematerialisation indicator should not currently be covered by efficiency policy – fossil resources used for energy production should thus be excluded.
- The prime aim of a dematerialisation indicator at present is to capture (changes in) material flows at the national level. In a follow-up study, however, dematerialisation policy could be further elaborated at the level of individual firms, using LCA for example.
- According to NEPP4 it is above all at the level of basic products that resource flows should be measured. This is confirmed by our analysis of the possible scope for a dematerialisation indicator with reference to the experience gained with energy indicators.
- Experience with (energy) efficiency indicators suggests that a dematerialisation indicator should be based on consumption and not on production. NEPP4, however, seems to suggest that one of the aims of a dematerialisation indicator should be to reduce resource use by Dutch producers. This is reinforced by the emphasis placed on the possible role of dematerialisation in securing climate policy targets, for the Kyoto commitments refer to the CO_2 emissions associated with goods *produced* in the Netherlands. In the following chapters we have opted to elaborate both approaches.
- There is no simple answer to the question whether material flows should be weighted for environmental impact. In the remainder of this study we therefore develop environmentally weighted as well as unweighted indicators, so that a reasoned choice can later be made on the basis of practical examples.

4 Ten material flows analysed

In the previous chapter we argued the basic, preliminary choices to be made before embarking on actual development of a dematerialisation indicator. In this chapter we take the first steps towards actual indicator construction by describing trends in the material flows of ten selected basic materials[16]. We also analyse the environmental burden associated with consumption of each of these materials.

4.1 Choice of flows

In consultation with the ministry commissioning this study, ten major bulk material flows were selected for inclusion in a dematerialisation indicator, namely:

1 Naphtha.
2 Steel.
3 Aluminium.
4 Copper.
5 Wood.
6 Paper / Cardboard.
7 Cement.
8 Sand.
9 Chlorine.
10 Soybeans.

These materials were selected for two reasons: for their volume and because they appear to embody a broad spectrum of environmental problems, ranging from climate change to acidification and from landscape damage to waste. In addition, we anticipate that this selection will give a good idea of the various problems likely to be encountered in developing a dematerialisation indicator.

Together these material flows represent the main material categories, viz.:

- metals: steel, aluminium and copper are the three most important in volume terms;
- industrial minerals: sand and cement, both high-volume;
- 'short-cycle' organic: wood, paper / cardboard and soybeans are all major bulk products;
- chemicals: chlorine and naphtha are again key bulk products.

In addition, these materials provide a good opportunity to explore the problems associated with imports and exports. Soybeans and copper are not produced in the Netherlands but imported exclusively from abroad. In contrast, the country is a major exporter of naphtha, aluminium and steel.

As argued in chapter 3, we base our calculations here on 'apparent consumption', i.e. production plus imports minus exports of the materials in question. With the limited subset of materials selected here, this approach can do no more provide an *indication* of true resource consumption by Dutch

[16] As explained in the previous chapter, we employ the term 'basic material' to mean both primary materials and semi-manufactured products: in the case of steel, for example, plating, slabs, pipes and tubing.

construction and industry. Note that in apparent consumption stockpiling is counted as extra consumption and stock withdrawal as reduced consumption. This has the effect that for some years consumption is relatively high (due to stockpiling) and in the subsequent year relatively low (because of release of the stock). Several materials selected here showed such peak levels in 1990 and 1995. Reasons for this were not investigated in this research, but could be due to (anticipated) price changes on the international markets.

For all these materials we inventoried production, import, export and recycling volumes[17]. In addition, for each of the selected materials data were gathered on three forms of environmental impact: climate change, to which CO_2 emissions make the greatest contribution, final waste and land use. This will enable us to examine the effect of weighting the material flows according to their environmental impact.

A range of sources were consulted for data, including Netherlands Statistics (CBS), International Trade Commodity Statistics (ICTS) and other statistical offices as well as the International Energy Agency (IEA), trade associations and a variety of business contacts (Shell, Akzo Nobel, Corus, Nedstaal). The precise development of each material is described in the Annexes of the Dutch report. A reference list of the sources consulted is provided in the literature section.

4.2 Estimating environmental burdens

To gain an impression of the environmental impact of dematerialisation, let us now examine whether and how the environmental burden of these ten material flows can be incorporated in the indicator. We shall keep this analysis limited, because this is a complex issue that cannot be adequately covered within the present project. In this section we merely set out arguments for several key choices and limitation of our scope.

4.2.1 Environmental policy themes

Materials consumption and production are associated with a wide range of environmental impacts. In discussions with the ministry commissioning the study the following environmental policy themes were cited as being potentially relevant for a dematerialisation indicator:
- climate change;
- acidification;
- groundwater depletion;
- land use;
- biodiversity;
- toxicity;
- final waste.

Three of these themes were selected for further elaboration: climate change, final waste and land use. Climate change was selected because NEPP4 mentions this as a key motive for dematerialisation policy. Final waste and land use, for their part, often play a key role in discussions on dematerialisation, for it is held that so-called ‘hidden flows’ are of major influence on these two categories of environmental impact. One of our aims below, therefore, is

[17] As we shall see in chapter 5, there are alternative perspectives on how these recycled flows should be incorporated in the indicator.

to see whether these can be included in the analysis differently from how this is normally done in the Total Material Requirement (TMR) methodology.

In the present phase of elaborating an indicator for dematerialisation, then, we shall ignore the other environmental themes, for the reasons summarised briefly below.
- ccidification: these emissions are largely parallel to those contributing to climate change;
- groundwater depletion: this theme is too site-specific for suitable data to be available;
- biodiversity: although there is presently great interest in this policy theme, there is still no proven method of quantification. There are also likely to be parallels with land use, which is included in the indicator;
- toxicity: this theme is concerned with relatively small-scale emissions of toxic substances posing a severe threat to human health. In our view dematerialisation is not the appropriate tool for reducing these emissions, for which more stringent regulations are needed.

In the following section we elucidate the methodological choices made in estimating the environmental burden of the ten selected materials in terms of the three themes of climate change, final waste and land use. The specific values for each of these impacts are reported in paragraph 4.2.6 and calculated in the Annex A (available in Dutch only).

4.2.2 Cradle-to-grave impacts

As they pass through the economy, materials undergo a variety of processing steps, with production of the basic material but one of many links in the supply chain (Figure 1). An important question in constructing a dematerialisation indicator is whether only those environmental impacts associated with basic materials production should be assessed, or whether upstream and downstream impacts should also be included.

Here we have opted to include the environmental burden along the entire supply chain, ‘from cradle to grave’, wherever feasible. We feel it is unduly restrictive to limit the environmental burden of materials use solely to the basic production step. After all, minerals recovery and concentration processes are associated with multiple environmental impacts. With certain materials, moreover, usage also has implications for the waste disposal phase of the life cycle, with some materials harder to process than others. We have endeavoured to include all these effects. In the case of consumer products like vehicles and appliances, though, we have ignored the manufacturing as well as use phases. Here again it is clear that the virtually limitless range of products on the market precludes calculation of the true environmental burden of each and every one.

Summarising, the environmental impact analysis undertaken here covers the following links in the supply chain:
- links prior to product manufacture, viz. resource recovery, concentration and production of semi-manufactures[18];
- links subsequent to product use, viz. waste processing and possibly recycling.

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[18] The environmental impact of each of these phases is highly dependent on the country in which they take place, i.e. on the economic ‘country of origin’. For this reason we have taken an ‘average environmental burden’ wherever possible.

For the waste disposal phase we have based ourselves on processing in a state-of-the-art Dutch waste incinerator. Although some waste is still landfilled rather than incinerated in the Netherlands, this cannot be allocated to specific material supply chains. This landfilling is the outcome of government waste policy, with supply chains having no bearing at all. This does not hold for the incinerator ash and emissions, though, which can be allocated to individual materials, a point we shall return to later.

4.2.3 Climate change

The main cause of climate change are CO_2 emissions, chiefly a function of the amount of energy consumed in the processes comprising the supply chain. With some materials, energy-related CO_2 emissions may not be the sole contributor to climate change, though. In the case of aluminium, for example, emissions of perfluorocarbons (PFC) during basic metal production may also be a major contributing factor. With cement there are additional, chemical CO_2 emissions[19]. All these emissions have been included in our analysis.

Another item of interest are the CO_2 emissions occurring during waste disposal. When organic matter like paper or wood is ultimately incinerated (following one or more rounds of recycling) it is part-converted to CO_2. These emissions have not been included in the inventory because the CO_2 involved was absorbed from the air by tree foliage in the recent past ('short-cycle' CO_2)[20]. Naphtha, on the other hand, is produced from a fossil resource (crude petroleum) and the incineration of plastics made from this naphtha does contribute to climate change. This CO_2 emission is long-cycle as well as material-specific and has therefore been included in the inventory.

One methodologically important feature of waste incineration is that a certain amount of process heat is generally recuperated as energy, thus obviating the need for recovery and refining of some quantity of fossil fuels, with their associated CO_2 emissions. These avoided CO_2 emissions have been omitted from our analysis, because this is regarded as an indirect effect resulting from waste policy rather than from the use of the material itself.

4.2.4 Final waste

Final waste is defined here as waste ultimately disposed of in a landfill site after a varying number of (re)processing steps. It is thus the landfilled fraction of the overall waste flow in question. There is often confusion between 'final waste' and other waste categories, including in particular:

1 Production waste arising during resource recovery and processing and energy carrier production. This waste is generally subject to further processing and is not necessarily disposed of as final waste in landfill.
2 Waste incineration residues (fly ash, bottom ash, slag), much of which is usefully applied, with only some being disposed of in controlled landfills. Only the latter fraction counts as final waste.

It is not always possible to pronounce unambiguously on whether a particular waste stream should be classified as final waste. A wide range of waste categories and subcategories are to be found in the environmental literature,

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19 $CaCO_3 + SiO_2 + heat \rightarrow CaSiO_3 + CO_2$.

20 For the same reason we have not included the short-cycle CO_2 absorbed from the atmosphere during growth of soybeans.

and in some cases it is not entirely clear whether or not they are final waste for landfill. In the case of plastics, for example, there is considerable debate on the status of the mining spoil generated during fossil resource recovery (i.e. coal, oil or gas). In practice this kind of waste is generally used for re-landscaping following mine closure. This can be regarded as a form of recycling and it is therefore questionable whether this is 'final waste for landfill'. Because of the enormous volumes involved, however, this category is of major influence on the final analytical outcome.[21]

The following table shows the main categories of waste and the extent to which these have been counted as final waste in this study. They are discussed individually below.

Table 2 Waste categories: final waste or not?

	Waste category	Final waste?
1	Mining spoil	Not final waste
2	Slag and ash from basic materials production	If usefully applied, not final waste
3	Hazardous waste	Without further processing, final waste
4	Industrial waste similar to domestic waste	Not final waste
5	Fly ash from domestic waste incinerators	50% final waste
6	Slag from domestic waste incinerators	Not final waste
7	Flue-gas treatment residues from domestic incinerators	Final waste

Mining spoil
The earth and rock spoil arising during mining operations, generally returned to their point of origin following mine closure.

Slag and ash from basic materials production
The slag and ash from the combustion processes associated with materials production and generation of the energy required for that production. This is often a vitreous substance and is then used in road-building because of its high resistance to leaching. It is then not counted as final waste. If it is not vitreous, the waste is sent to a controlled landfill site and is then final waste.

Hazardous waste
If this is reprocessed, recycled or put to useful purpose (within statutory criteria), it is not final waste. Conversely, if this is not the case, it does count as final waste.

Industrial waste similar to domestic waste
Waste from offices and canteens at industrial facilities. This is disposed of in the same way as domestic waste, i.e. by incineration.

[21] Another key factor determining the environmental burden of final waste is country of origin. In most western countries environmental criteria have established for waste streams, which can consequently often be usefully applied rather than being sent to landfill as final waste. In some non-western countries, however, certain forms of waste are not processed but landfilled and so would have to be counted as final waste. It is often anything but straightforward to establish country of origin, and such an exercise was beyond the scope of this study. In our environmental analysis of the waste phase we have therefore based ourselves on the 'western' environmental context. This is an issue that might be examined in more detail in a follow-up study to develop a more refined dematerialisation indicator.

Fly ash from domestic waste incinerators
Half of this is assumed to be usefully applied and half landfilled. In the case of paper 3.3% of incinerator feed ends up in the fly ash; this is 1% for wood, 20% for chlorine and 5% for plastics. None of the other materials considered here are converted to fly ash.

Slag from domestic waste incinerators
Incinerator slag is usefully applied in road-building and is therefore not final waste.

Flue-gas treatment residues from domestic incinerators
These residues are landfilled. Of the chlorine input to incinerators, 70% ends up in this fraction.

4.2.5 Land use

To calculate materials-related land use impacts is no easy matter and a variety of methodologies and perspectives on this issue have been developed. One of the best known is the ‘Ecological Footprint’ (see Wackernagel & Rees, 1996), an indicator expressing aggregate environmental burden (of a material) in terms of square metres. However, since in this study we have opted to make separate calculations of selected environmental burdens such as emissions due to energy use, we had no intention of using land use as an indicator for overall environmental burden. As such, then, the Ecological Footprint is not a suitable tool for assessing land use here.

Apart from the Ecological Footprint there are no nicely named theories at hand. However, there have been a variety of attempts to quantify land use within LCA methodologies[22] and strategic resource management analysis. There are two methodological dilemmas here:
1 How to deal with the temporal aspect of land use?
2 How to deal with changes in ‘land quality’?

These dilemmas are closely related, for square metres of land can never be lost, merely used for a different purpose for some length of time. Here we shall not immerse ourselves too much in this debate, however, but simply make use of the available data.

Land use data are available in a number of databases, including CBS, CORINE and IMAGE. However, all of these are concerned with the general land stock and land use by various broad sectoral categories like 'urban', ‘mining’ and 'recreation'. To convert these statistics to land requirements for specific materials therefore demands a series of additional calculations and assumptions. As they stand, then, these databases are not suitable for the present purpose[23].

Fairly extensive calculations have been made of the land use associated with sand and cement[24], and the same holds for wood and soybeans and a

22 Lindeijer *et al*. (2002); Harjono *et al.* (1996).

23 Employing an allocation procedure based on employment and added value, the Dutch consultancy Pré is currently using these databases to estimate the land use associated with selected materials. The results of this project, commissioned by the National Institute of Public Health & Environmental Protection (RIVM), will soon be available in SimaPro.

24 Lindeijer *et al*., (2002); Lindeijer *et al*. (1998).

range of other agricultural products (on the basis of FAO data)[25]. These calculations are relatively straightforward because here land use can be directly measured. In the case of aluminium, too, the amount of land associated with mineral extraction is well known[26]. These data sets employ different methodologies, however, and are not therefore directly compatible. The only source we know of that provides methodologically consistent land use data is IVAM [Ewijk *et al.*, 2000], who use raw data compiled by EcoQuantum. Unfortunately, though, the reliability of the IVAM estimates does not appear to be consistently high[27]. In the absence of a better alternative, however, in the next chapter we shall use these data in constructing our pilot indicators for dematerialisation.

4.2.6 Review of environmental indices

For each of the ten materials specified earlier, the following table shows the indices used for the three environmental impacts considered in this study.

Table 3 Environmental impact indices used in this study

	CO_2 (gram per kilogram)	Final waste (gram per kilogram)	Land use (m^2 year per tonne)
Naphtha	3,427	3	1.26
Steel, primary (0% scrap)	3,070	86	5.54
Steel, secondary (100% scrap)	1,180	10	0
Steel, average (20% secondary)	2,690	71	
Aluminium, primary (0% scrap)	12,833	1,403	1.26
Aluminium, secondary (100% scrap)	791	5	0
Aluminium, average (30% secondary)	9,220	983	
Copper, primary (0% scrap)	3,258	1,022	1.26
Copper, secondary (100% scrap)	712	5	0
Copper, average (50% secondary)	1.985	514	
Wood	170	0	5.54-6170 (3000 average)
Bond and offset paper (0% old paper)	464	205	
Packaging paper (100% old paper)	615	1,3	
Sanitary paper (100% old paper)	367	0,064	
Paper, average (based on relative proportion of grades & 10 yr average lifetime)	539	45	5,54
Cement (av. 25% Portland)	446	0.005	5.54
Sand (25% concrete, 75% fill & perc)	3.5	NA	0.0018
Chlorine	1,200	1,391	5.54
Soybeans	1,002	70	4,004

25 www.faostat.com; Ros *et al.*, *Voetafdrukken van Nederlanders*, RIVM, Bilthoven, 2000; Elzenga *et al.*, *Het ruimtebeslag van Nederlanders, 1995-2030*, RIVM, Bilthoven, 2000 Lindeijer *et al.*, 2002; and Pré, 2002.

26 www.aluminiumcentrum.nl.

27 Chlorine, cement, paper and steel all have exactly the same land use index, as do naphtha, aluminium and copper. The data for wood seem inconsistent, moreover: 'spruce logs' require 6.17 m^2 of land per kg, while 'spruce profile', a kg of which is made from 4.13 kg of logs requires only 0.00514 m^2 per kg. We found no explanation for these facts.

5 Dematerialisation indicators

Equipped with the data set for the ten selected material flows described in the previous chapter, we proceeded to actual construction of pilot dematerialisation indicators. The main aim of this chapter is to illustrate the choice of indicators available (section 5.1), examine their constitutive elements and assess their performance in expressing trends of interest (section 5.2). We conclude by comparing their performance and discussing the main pros and cons of each in relation to the analysis of chapter 3 (section 5.3).

5.1 Choosing among potential indicators

For each of the materials, our data set comprised statistics and indices on the following:
- production;
- imports;
- exports;
- recycling;
- environmental impacts (here: climate change, final waste and land use).

A great many indicators can in principle be constructed using this information. In doing so, there are a number of key choices to be made:
1. Is the indicator to be based on production or (apparent) consumption of the selected materials?
2. Is the aggregate materials flow to be measured, or only the flow of virgin materials, i.e. ignoring recycling (Virgin material flow = Total material flow – Recycling)?
3. Are the material flows to be summed (weighted) according to mass, environmental impact or a statistical weighting method?

In chapter 3 we argued that the main aim of a dematerialisation indicator should be to support a materials policy geared to improving materials efficiency. As discussed there, this implies that the indicator should be based on materials *consumption*, for materials production says very little about the efficiency with which materials are processed. On the other hand, NEPP4 expresses a preference for linking up to the production side of materials use in the Netherlands. Below, then, we shall elaborate both types of indicator.

If the concern is purely to improve materials efficiency, recycling should not be included in the indicator. After all, it should make no difference to production process efficiency whether virgin or recycled materials are employed. On the other hand, there are good reasons to believe that an indicator that ignores recycling may send out the wrong signal: reducing product weight by substituting a recycled for a virgin material is not always environmentally beneficial. One of the aims of this chapter is therefore to consider what difference it makes if recycling is included in the indicator.

With respect to weighting, finally, it is as yet unclear which form of weighting is most appropriate for a dematerialisation indicator. Below, we shall therefore explore a variety of methods.

5.2 Four perspectives on dematerialisation

Dematerialisation policy, defined as resource efficiency policy geared to reducing the environmental impact of material resource use, can be fleshed out in a variety of ways. Below we examine four perspectives on such policy, presenting several alternative indicators in each case. In this section we first consider the indicator numerator, i.e. the summed and possibly weighted material flows, turning in chapter 6 to the denominator, i.e. the efficiency with which the flows in question are used.

5.2.1 Reduction of materials throughput

Perspective
In this first option the basic aim is to reduce the aggregate flow of materials through the economy per unit GDP. The underlying science is based on the work of Georgescu-Roegen (1971) and Daly (1991). Key in this approach is the notion of ‘throughput’, defined by Daly as the entropic flow of materials and energy through the economy. Important here is the concept of entropy, a rather abstract measure of the ‘unavailability’ of energy and information. Materials and energy cannot be destroyed, merely transformed from a low-entropy to a high-entropy state (from refined fossil fuels to CO_2 and heat, for example). For Georgescu-Roegen and Daly, recycling and materials substitution are no solution to scarcity, as recycling always requires additional energy.

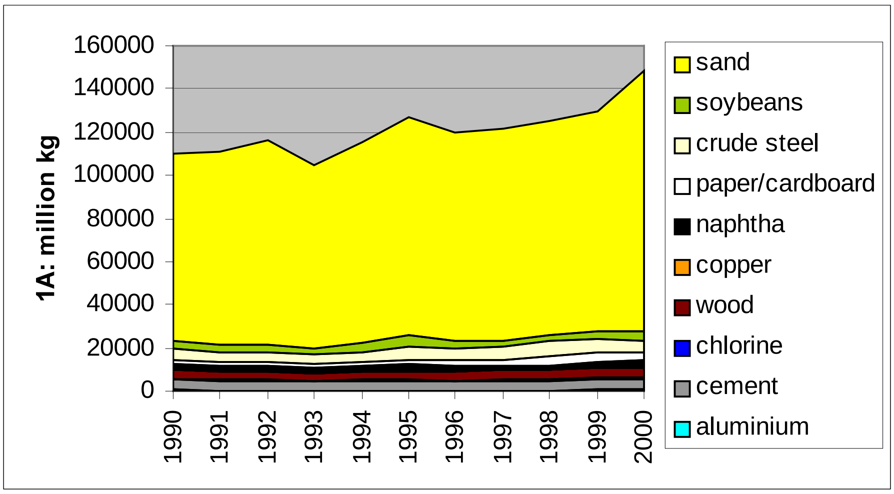
This perspective has its strongest advocates among people and organisations who hold that Western societies are living beyond their means: our compulsive consumption is leading to resource depletion and environmental degradation at home and around the globe. Reducing materials throughput is seen as a fundamental, source-based strategy to address these issues.

Indicator
The first variant examined in this context is an indicator based on materials consumption, with flows weighted by mass and no correction made for recycling. For convenience’s sake, in treating each pilot indicator we review these choices in tabular form, as below:

Indicator 1A: Materials throughput, mass-weighted

Based on		*Weighting*		*Corrected for recycling?*	
☐	Production	■	Mass	■	No
■	Consumption	☐	Environmental impact	☐	Yes
		☐	Statistical	☐	Weighted

Figure 4 Indicator 1A: Materials throughput, mass-weighted



As measured by this indicator, dematerialisation is steered predominantly by sand, which has a throughput five times greater than all the other flows combined. Between 1990 and 2000 the dematerialisation indicator rose by nearly 35%, more than growth of GDP (+33%). In this period, then, there was in fact *rematerialisation* rather than dematerialisation, as already noted by De Bruyn (1998).

The predominance of sand in the picture obtained with this indicator is clearly undesirable. Partly for this reason, some dematerialisation studies (cf. Jänicke *et al.*, 1989; De Bruyn & Opschoor, 1997) choose to focus on *changes* in the indicator. This would normally be done by indexing the data to a reference year (e.g. 1990 = 100) and then weighting each material equally. However, the objection here is that an arbitrary year may often give a skewed impression. The year 1990 may have been a year with a great deal of materials stockpiling, for example, or a lot of road-building, yielding a relatively high figure for consumption of the materials in question in the reference year. The method adopted in Jänicke *et al.* (1989) was not to index the indicator to a specific year, then, but to the long-term average, to prevent annual extremes unduly influencing the overall indicator[28]. In the second variant of this throughput indicator, we did the same.

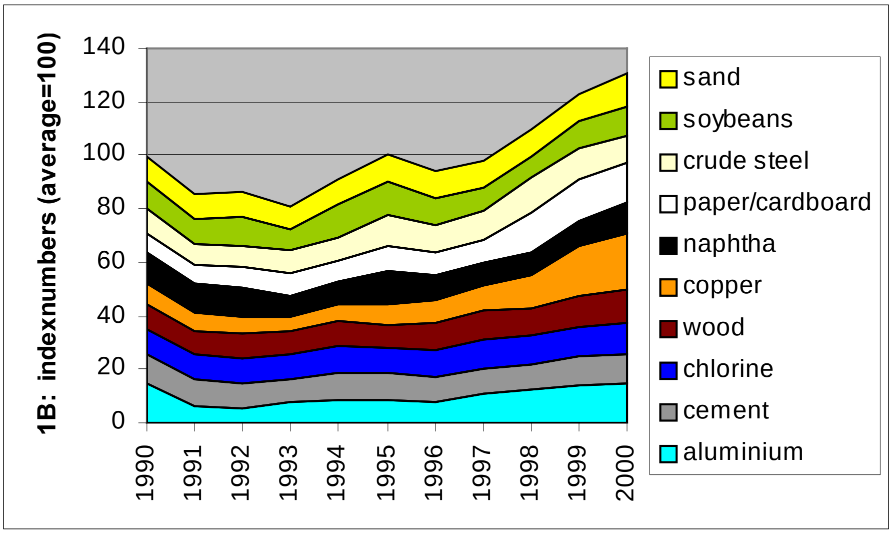
Indicator 1B: Materials throughput, statistically weighted

Based on		*Weighting*		*Corrected for recycling?*	
□	Production	□	Mass	■	No
■	Consumption	□	Environmental impact	□	Yes
		■	Statistical	□	Weighted

The trends measured by this statistically weighted indicator are shown in the following figure.

[28] Compared with a simple indexing method, this means the material flows are weighted relative to one another over the entire 10-year period rather than in a reference year such as 1990, thus better reflecting the contributions of the respective materials.

Figure 5 Indicator 1B: Materials throughput, statistically weighted



What is immediately striking is that the indicator gives similar expression to each of the flows. Throughput of paper and copper, in particular, appears to have increased substantially over the years. The general decline in the indicator, i.e. the trend towards dematerialisation, in the early '90s can be ascribed partly to the low rate of economic growth and partly to a decline in aluminium consumption, for which there is no obvious explanation. Another noteworthy feature is the peak in 1995. This is due mainly to a sharp rise in industrial consumption of naphtha and crude steel, possibly due to stockpiling[29].

Between 1990 and 2000 the throughput of materials in the Dutch economy rose by 31%, nearly equal to GDP growth over the same period (33%).

5.2.2 Reduction of virgin materials input

Perspective
In this second policy perspective, the main aim is to reduce inputs of virgin materials to the economy. In this context the metaphor of 'industrial metabolism' is often used, with the exchange of materials between the economy and the ecosystem being likened to the metabolism of biological organisms. In this perspective the key links in the materials supply chain are extraction and waste processing. Our pilot indicators now therefore include recycling, i.e. use of secondary materials, as this may specifically contribute to improved industrial metabolism.

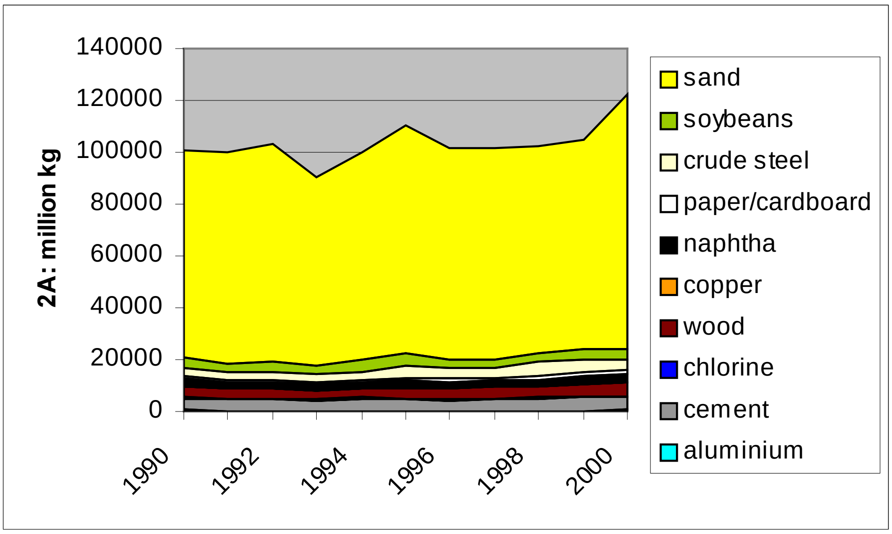
Indicators
The first indicator variant is obtained simply by summing the material flows on the basis of mass, focusing once more on materials consumption.

[29] Stockpiling is measured statistically as consumption.

Indicator 2A: Industrial metabolism, mass-weighted

Based on		*Weighting*		*Corrected for recycling?*	
□	Production	■	Mass	□	No
■	Consumption	□	Environmental impact	■	Yes
		□	Statistical	□	Weighted

Figure 6 Indicator 2A: Industrial metabolism, mass-weighted



Once again, sand is found to predominate in the picture yielded. Between 1990 and 2000 the indicator rose by 22% overall, less than GDP growth. The lower growth compared with indicator 1A indicates that more materials are now recycled in the Netherlands than in 1990. This holds for sand, particularly, as the following table shows.

Table 4 Recycling percentages of materials considered in this study

Material	**1990**	**1995**	**2000**
aluminium	23%	23%	23%
paper / cardboard	70%	72%	72%
crude steel	23%	22%	21%
sand	8%	13%	19%

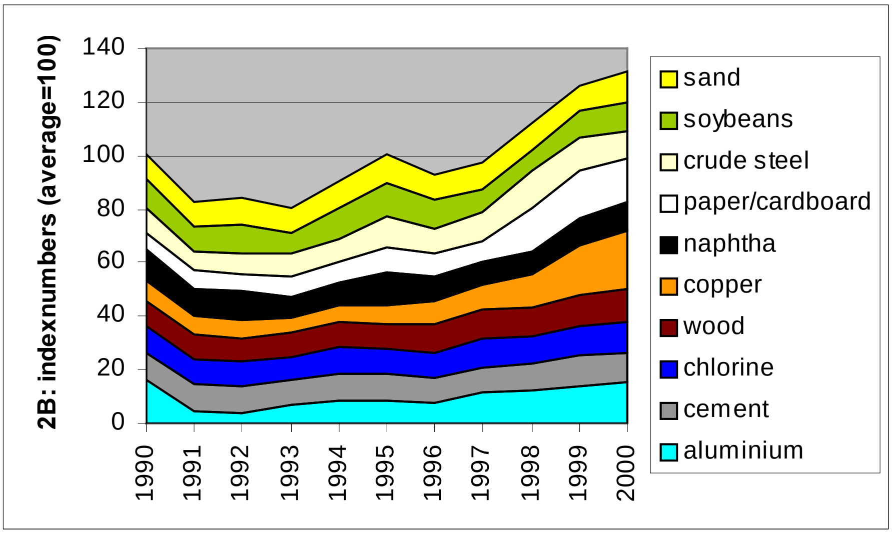
NB: Materials not included in this table are not recycled.

Because sand is so dominant in this indicator, there appears to be substantially more recycling now than ten years ago. As discussed under indicator 1A, this unwanted dominance can be obviated by applying statistical weighting to map *changes* over time. This yields the following picture:

Indicator 2B: Industrial metabolism, statistically weighted

Based on		*Weighting*		*Corrected for recycling?*	
□	Production	□	Mass	□	No
■	Consumption	□	Environmental impact	■	Yes
		■	Statistical	□	Weighted

Figure 7 Indicator 2B: Industrial metabolism, statistically weighted



Now the materials all contribute evenly to the indicator. The share of copper, in particular, has grown substantially over the years. Again, there are conspicuous peaks in 1990 and 1995.

Between 1990 and 2000 this dematerialisation indicator showed an increase of almost 31%, almost the same as GDP growth. This rise is identical to that found with throughput indicator 1B. As can be seen, if sand is taken as just one of equally weighted flows, there has been little increase in recycling.

5.2.3 Contribution to environmental policy

Perspective

In this policy perspective the main aim of dematerialisation is to help secure national environmental targets such as those for greenhouse emissions or final waste. This pilot indicator therefore focuses on domestic materials production, as most key environmental targets (CO_2, VOC, fine particulates and acidifying emissions) pertain to Dutch industry and to emissions within national borders. In addition, the main environmental impacts associated with the selected materials occur during the production phase of the life cycle rather than in usage.

In this case there is no point in weighting flows on the basis of mass. They should be weighted, rather, for their contribution to environmental themes of policy interest. Recycling is beneficial to the precise extent that it reduces the overall environmental burden, and in computing the burden associated with basic materials production we therefore distinguish between primary and secondary inputs, constructing a specific environmental profile for each.

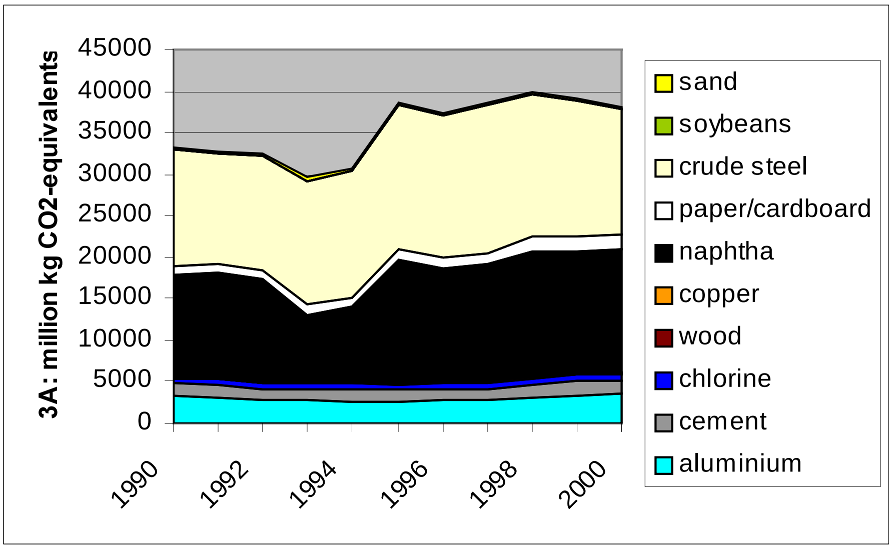
Below we examine three indicators of this kind, for each of the environmental policy themes selected above: climate policy, waste policy and land use. All are of the same basic form:

Indicator 3: Contribution to environmental policy indicator, general form

Based on		*Weighting*		*Corrected for recycling?*	
■	Production	□	Mass	□	No
□	Consumption	■	Environmental impact	□	Yes
		□	Statistical	■	Weighted

Indicator 3A: CO_2 indicator

Figure 8 Indicator 3A: Contribution to environmental policy: CO_2



As the figure shows, dematerialisation, weighted according to the contribution of domestic production to greenhouse emissions, rose between 1990 and 2000 by over 15%. This is more than the overall increase in Dutch greenhouse emissions over the same period (+ 8.7%). This might be regarded as a sound motive for instigating dematerialisation policy (reductions in emissions associated with materials production lagging behind reductions in the domestic economy as a whole), but it should be noted that the weighting factors used here are valid for a single reference year only, rather than being computed each year anew. This means they do not reflect annual changes in emissions of CO_2-equivalents[30].

The figure also shows that a mere handful of materials is responsible for the bulk of greenhouse emissions due to materials production: steel and naphtha, and to a lesser extent aluminium. To provide some context: these ten materials are responsible for around 15% (about 30 Mtonne) of aggregate Dutch emissions of CO_2-equivalents. This figure is almost twice as high as that assumed in NEPP4 (8%), however. On the one hand, this may indicate that basic materials production is implicated more in the climate change problematique than previously thought.

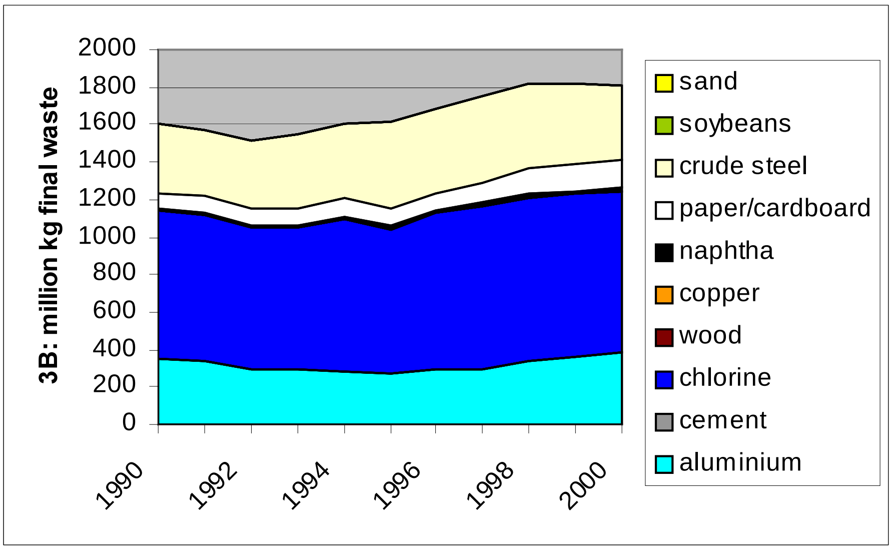
[30] If there were major changes in modes of production, weighting would have to be adjusted.

On the other hand, in this study we have in principle considered the environmental effects of materials use from cradle to grave (see chapter 4) rather than merely in the production phase[31].

Indicator 3B: Final waste indicator

Weighting Dutch production of the ten selected materials according to their contribution to the policy theme of 'final waste' yields the following trend in dematerialisation:

Figure 9 Indicator 3B: Contribution to environmental policy: final waste



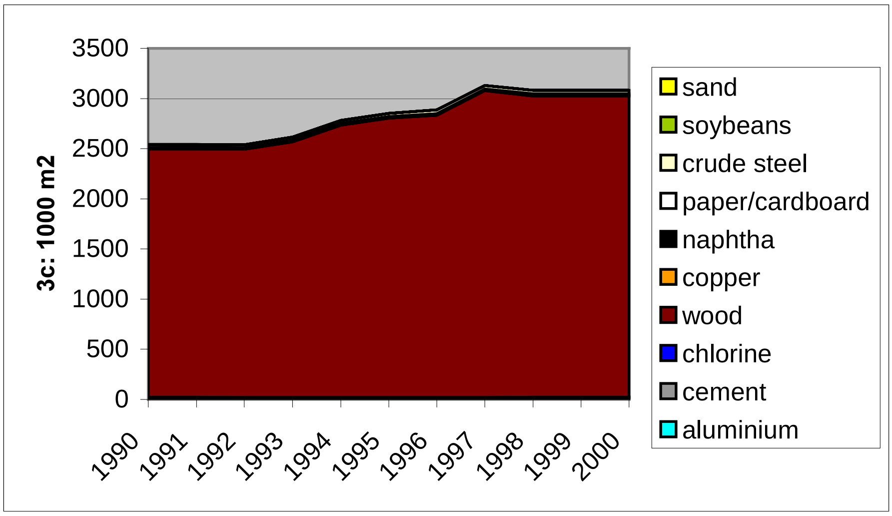
With a dematerialisation indicator weighted for final waste, four flows are responsible for overall trends: crude steel, paper/cardboard, chlorine and aluminium. There is no domestic production of copper, soybeans or wood, and the final waste impact of sand, cement and naphtha is negligible. Between 1990 and 2000 this dematerialisation indicator rose by over 13%, less than GDP growth over the same period.

Indicator 3C: Land use indicator

Measuring dematerialisation in terms of the land use impact of Dutch basic materials production yields the following picture:

31 As an example, the total emissions of the basic metals industry according to Netherlands Statistics (CBS) are less than our calculations for aluminium, steel and copper production. There are also doubts regarding the environmental profile of crude steel, in particular; the available data are outdated and possibly overestimated in our database (see Annex A).

Figure 10 Indicator 3C: Contribution to environmental policy: land use



As can be seen, the land use impact of Dutch basic production is entirely dominated by just one material: wood. This is hardly surprising, because apart from sand there is no domestic extraction or harvesting of materials and the (long-term) land use impact of sand recovery is limited. This demonstrates that if one of the policy aims of dematerialisation is to address problems of land use, the indicator would have to be extended to include other materials.

It should be noted, finally, that the land use database on which these results are based is very fragmentary and that new data might well alter the picture recorded here (see discussion in chapter 4).

5.2.4 Environmental impact of Dutch consumption

Perspective
In this perspective the policy aim is to improve the environmental efficiency of materials consumption, understood as a reduction in the environmental burden associated with that consumption, whether in the Netherlands or elsewhere. Here again there is no point in aggregating flows on the basis of mass, which bears little relationship to the ultimate environmental impact of usage. This perspective is advocated by those concerned that the main burden of Dutch materials consumption is borne by other countries. This was originally one of the main arguments in Dutch parliament to introduce a dematerialisation policy (the Steenhoven/Augusteijn-Esser parliamentary motion).

Indicator
As with the third group of indicators, above, we here examine three indicator variants based on (apparent) consumption and weighted respectively for three environmental impacts. Recycling is included, as with indicator 3, by incorporating differences in impact between virgin and secondary materials. The general form of this indicator is as follows:

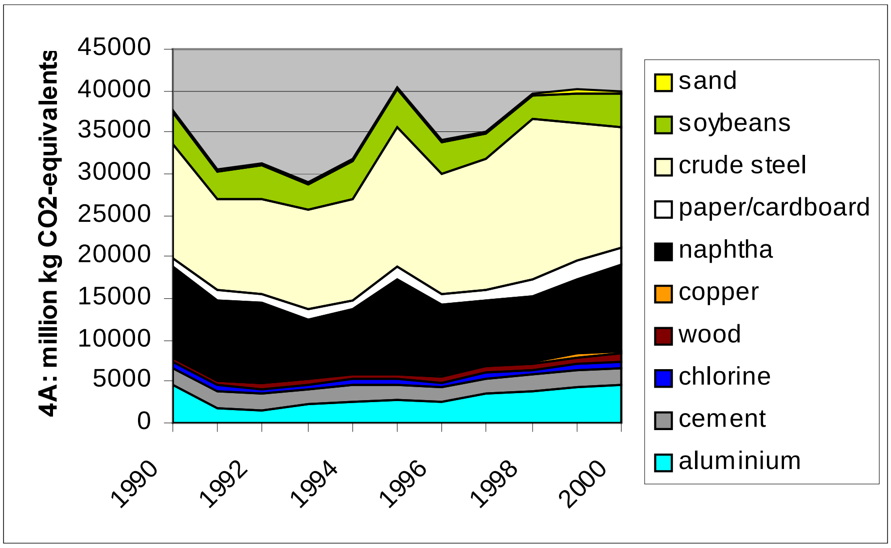
Indicator 4: Environmental impact of Dutch consumption, general form

Based on		*Weighting*		*Corrected for recycling?*	
□	Production	□	Mass	□	No
■	Consumption	■	Environmental impact	□	Yes
		□	Statistical	■	Weighted

Indicator 4A: CO_2 indicator

This indicator shows that the climate impact of Dutch materials consumption increased by 6% between 1990 and 2000. This is less than the increase in climate impact associated with domestic production of these materials (indicator 3A). This signals that, for the basic materials selected, domestic production outstripped consumption in the same period. It should be added, though, that the relatively minor increase in this case may also be due to the choice of 1990 as reference year. If 1993 had been taken, for instance, the indicator would have risen far more, by 37%, considerably more than GDP.

Figure 11 Indicator 4A: CO_2 impact of Dutch consumption



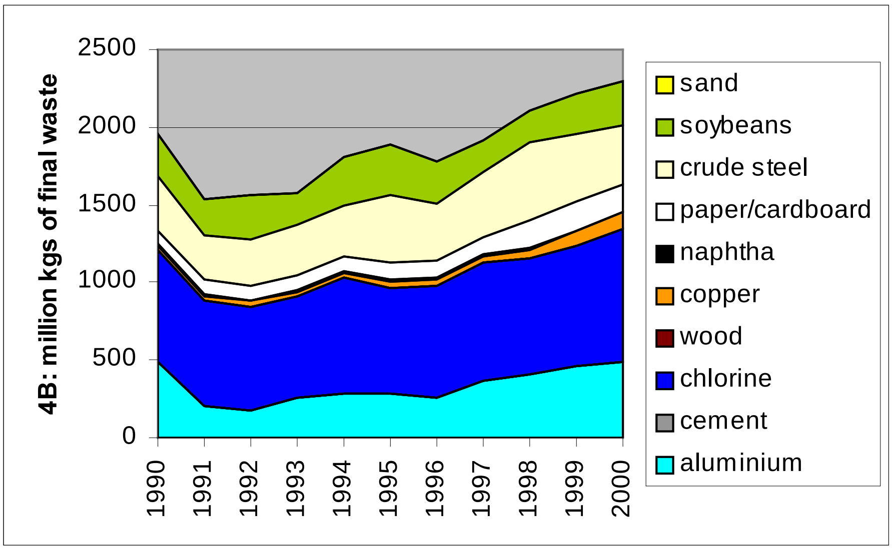
Besides aluminium, naphtha and crude steel, soybean consumption is now also a substantial source of CO_2(-equivalents). Another notable feature is the peak in 1995, probably a result of steel and naphtha stockpiling, as mentioned earlier.

Note that in 2000 the CO_2 emissions associated with Dutch materials consumption were about 5% higher than production-related emissions. For the chosen set of materials, then, the Netherlands is apparently a net importer of 'climate-intensive' materials.

Indicator 4B: Final waste indicator

An indicator weighting Dutch materials consumption according to final waste impact yields the following picture.

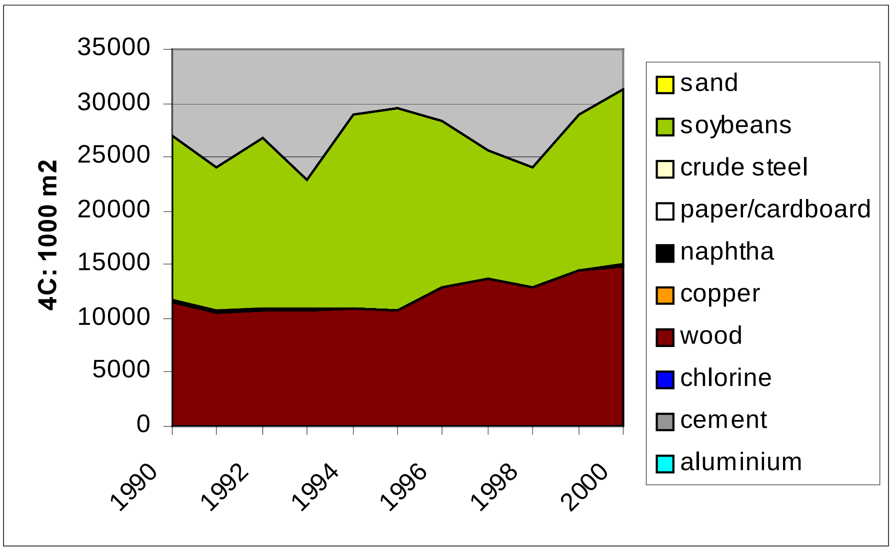
Figure 12 Indicator 4B: Final waste impact of Dutch consumption



On this indicator, dematerialisation rose by over 17% between 1990 and 2000. Although the final waste impacts of soybeans and copper, with no domestic production, can be discerned, their contribution is minimal in comparison with that of domestically produced materials (cf. indicator 3B).

Indicator 4C: Land use indicator
Weighting Dutch materials consumption for its impact on land use gives the following picture of dematerialisation.

Figure 13 Indicator 4C: Land use impact of Dutch consumption



In contrast to indicator 3C, soybean consumption is now also an important factor. The marked fluctuations in the indicator follow those in soybean production; as mentioned in chapter 4, consumption may have been influenced by variations in market prices and stockpiling levels. This dematerialisation indicator rose by over 15% between 1990 and 2000.

5.3 Evaluation: indicator preferences

In the previous section we presented the ten dematerialisation indicator variants developed within the framework of this study. Figure 13 below reviews the trends in all these indicators in a combined graph also showing GDP growth over the same period. The most striking feature is that not a single one of the indicators expresses a reduction in materials usage. In no sense, then, has there been any absolute delinking between materials consumption and GDP in the Netherlands. For some of the indicators assessed there has been at most *relative* delinking.

In establishing a preference among these indicators, we took recourse to both substantive and statistical arguments, which will in turn now be discussed.

5.3.1 Choices of substance

Although it may be preferable to base a choice for one or other indicator on substantive grounds, as argued in section 5.1 such grounds do not provide any direct guidance as to the precise kind of indicator required.

Recycling is one problematical area, for example. If one takes dematerialisation to measure no more than the efficiency with which materials are used in the Dutch economy, it may be wisest to leave recycling out of the analysis and simply focus on aggregate materials throughput. It may be objected, on the other hand, that recycling is a major incentive to reduce CO_2 emissions and final waste and that it would be environmentally short-sighted not to count this as dematerialisation. A second point is that if one of the indicators developed here were to be used at a later stage to set benchmark conversion ratios for specific industries, it would send out the wrong signal if materials tonnage were the only consideration, to the exclusion of materials origin. This is far less of a problem with indicators 3 and 4, which are based on the environmental impacts of materials usage and include the environmental burden of both virgin and recycled materials, setting them alongside one another. In our view this is by far the best way of accounting for recycling: by weighting it according to the respective environmental impact of virgin and secondary material flows.

Another issue is whether dematerialisation should be measured on the production or consumption side of the economy. To our mind, if dematerialisation is designed to monitor improvements in materials productivity, the indicator should be based solely on consumption. This would argue against indicators 3A, 3B and 3C. The aim, after all, is not to reduce production of a given material but its consumption.

Besides these considerations of substance, it is also worth examining whether there is any correlation between the indicators, so that trends in one indicator might tell us something about trends in another.

5.3.2 Statistical choices

Our aim here is thus to examine whether there is significant correlation between the pilot indicators. If this is the case, it may not be necessary to develop a dematerialisation policy incorporating all the indicators, for if some run parallel trends in one will permit fairly confident predictions with respect to the others.

As a cursory inspection of Figure 13 below, already shows, there is indeed a good deal of correlation. The following table gives the precise correlation coefficients between the respective indicators.

Table 5 Simple correlation coefficients between pilot indicators

	1A	1B	2A	2B	3A	3B	3C	4A	4B	4C	GDP
1A	1.00										
1B	**0.89**	1.00									
2A	**0.92**	0.77	1.00								
2B	**0.87**	**1.00**	0.74	1.00							
3A	0.74	0.73	0.57	0.73	1.00						
3B	0.74	0.85	0.47	0.85	0.83	1.00					
3C	0.75	0.74	0.47	0.73	0.84	**0.93**	1.00				
4A	0.74	**0.86**	0.67	**0.87**	0.83	0.72	0.65	1.00			
4B	0.81	**0.96**	0.66	**0.97**	0.73	0.88	0.78	**0.89**	1.00		
4C	0.70	0.60	0.77	0.58	0.35	0.28	0.34	0.53	0.55	1.00	
BNP	**0.88**	**0.88**	0.63	**0.87**	0.78	**0.93**	**0.92**	0.67	0.84	0.42	1.00

The values in bold mark a statistical correlation of over 85%, signalling relatively parallel indicators. Between indicators 1B and 2B there is almost 100% correlation, which means there is no point in taking both indicators on board in further policy development. The difference between indicators 1 and 2 lies in recycling. Apparently, then, this is not particularly important for the ultimate value of the dematerialisation indicator.

Between indicators 1A and 2A there is also a very high degree of correlation: 92%, but they exhibit little correlation with the others. This seems to be because both are dominated by one particular flow: sand. To our mind it would be unwise to have consumption of sand steer a dematerialisation indicator and these variants do not therefore seem a viable option.

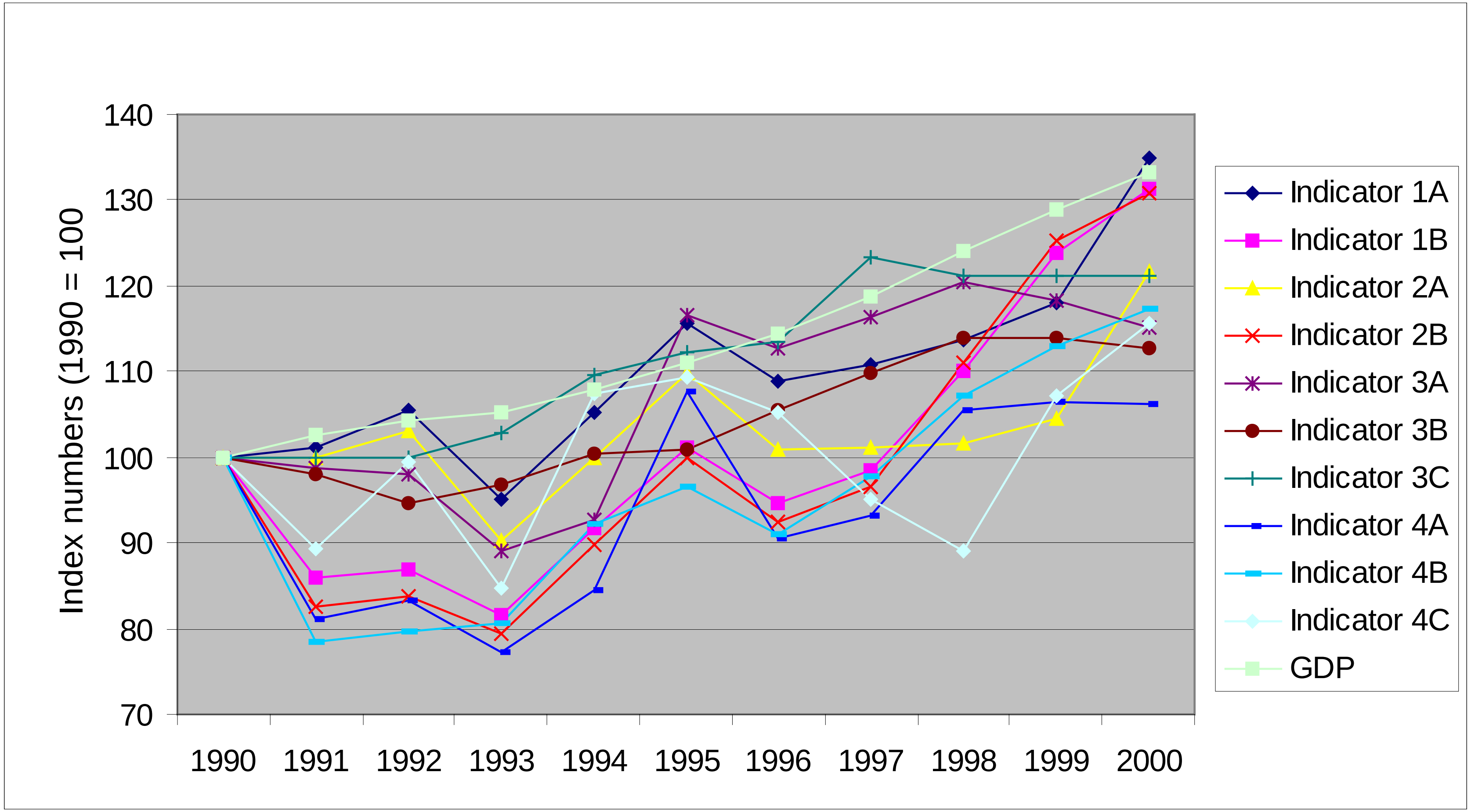
There is also very substantial correlation between indicators 4B and 1B/2B. This indicates that there may be no need for a separate indicator for final waste, because the statistically weighted indicator already adequately covers this particular environmental issue.

It is also conspicuous that indicator 3A bears relatively little correlation with any of the others, implying that a separate indicator for the CO_2 impact of Dutch production may be desirable if dematerialisation policy is to contribute to securing climate policy targets.

The two land use indicators (3C and 4C) also show little correlation with the others. Because just one or two materials predominate in both, we suggest it may be better to choose other materials for monitoring land use impacts.

A more formal method of choosing from among the ten pilot indicators is to apply factor analysis. By breaking down a set of quantitative variables (the ten indicators) into a limited number of factors, underlying relationships can be made more transparent. Thus, factor analysis may demonstrate, for example, that indicator 1A gives a better picture of overall environmental burden than indicator 1B, or vice versa. Subjecting our data set to this kind of factor analysis is beyond the scope of the present project, but such an exercise might well be useful in any follow-on study.

Figure 14 Dematerialisation according to the full set of pilot indicators



5.3.3 Preferred indicators

In summary, then, substantive and statistical arguments lead us to single out two indicators as holding out greatest promise for further elaboration: indicator 2B (Industrial metabolism, statistically weighted) and indicator 4A (CO_2 impact of Dutch consumption). This choice is based on the following arguments:

1 The aim of a dematerialisation indicator is to improve the efficiency with which materials are used in the Dutch economy. An indicator based on consumption (i.e. indicators 1, 2 and 4) is therefore preferable to one based on production.
2 Indicators 1 and 2 (A and B) correlate very strongly and there therefore seems to be no point in including both indicators in the analysis.
3 Variant B of both these indicators, 1 and 2, seems preferable to variant A, in which sand predominates over all other materials, even though it is of little significance environmentally[32].
4 Because recycling generally makes environmental sense, it seems right to include it in a dematerialisation indicator. This leads us to argue for indicator 2. In doing so, we are aware that this implies a *de facto* extension of the kind of dematerialisation policy outlined in chapter 3, where recycling was held to fall under a different policy heading. It may be added that it makes little difference in statistical terms whether indicator 1B or 2B is chosen, because the two correlate almost perfectly.
5 An indicator in which materials are weighted according to their environmental impact seems preferable to one in which all material flows are weighted equally (as with indicator 2B). The problem, though, is that environmental impacts come in a wide variety. Indicator 2B may therefore well be able to provide some kind of guarantee vis-à-vis the full spectrum of such impacts. The correlation coefficients indeed show that the information provided by an indicator geared specifically to final waste is sufficiently covered by indicator 2B. In contrast, inclusion of a separate CO_2 indicator (indicator 4A) would appear to be useful, all the more so because we too are of the opinion that the impact of Dutch materials consumption abroad is an important policy issue.

In the next chapter we shall first examine how the most promising indicators, 2B and 4A, relate to the financial value of the material resources and to GDP. We then consider how these indicators might best be further elaborated in the future, with reference to two scenarios.

In this exercise we shall include indicator 3A alongside indicators 2B and 4A, not because we deem it a useful yardstick for dematerialisation, but because it can be used to improve understanding of the part dematerialisation might play in meeting the Kyoto climate commitments – which in NEPP4 are cited as a key goal of dematerialisation policy.

5.4 Concluding remarks

In this chapter we have presented ten pilot indicators for dematerialisation and tested them on a set of ten bulk material flows. In the indicators in which materials flows were weighted by mass, sand proved to dominate the overall results. If this kind of indicator were desired, it would in fact be sufficient

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[32] Calculation of simple correlation coefficients shows that indicator 1A charts dematerialisation as being 99.3% identical to the trend in sand consumption and indicator 2A to 97.7%.

simply to monitor the flow of sand, for trends in sand use correlate tightly with overall trends in these indicators. We cannot see this being the goal of dematerialisation, however, and we therefore feel a choice for aggregation based on sheer tonnage would be undesirable.

The alternative is to use an indicator in which flows are weighted according to environmental impact and/or by using statistical methods designed to map *changes* in material flows. To our mind these are both acceptable propositions: weighting by environmental impact has the great advantage of dematerialisation immediately telling us something about the environmental gains of reduced materials usage. These approaches were found to be practically viable using the available data on familiar environmental problems like CO_2 emissions and final waste. By and large, the required data have been established in Life Cycle Assessment studies and are in themselves probably sufficient to elaborate a dematerialisation indicator.

One problem in assessing environmental impacts, however, is that there are countless forms of environmental burden, not all of which have been inventoried or analysed equally effectively. It thus proved fairly hard to make any precise estimate of the land use impacts of the material flows and in addition the land use indicators developed here were dominated by wood, i.e. forests and woodland. This tells us nothing about the landscape quality associated with these forests, though. And it seems a rather peculiar set-up to regard more woodland as rematerialisation.

Ultimately, we selected two indicators as being most suitable for monitoring dematerialisation:

1 An indicator for industrial metabolism, measuring the statistically weighted trend in industrial consumption of virgin materials (= total materials throughput minus recycling).
2 An indicator for the climate (i.e. CO_2) impact of domestic consumption, in which consumption of both virgin and recycled materials is weighted for greenhouse gas emissions ‘from cradle to grave’.

In addition, we shall examine below the role dematerialisation might play in working towards the Kyoto commitments, using the indicator measuring the climate impact of domestic production, as this was put forward in the NEPP4 as an important goal of dematerialisation policy.

In the next chapter we consider these three indicators in greater detail.

6 Dematerialisation indicators: a closer look

In this chapter we subject the most promising dematerialisation indicators of chapter 5 to further analysis. First we examine how they relate to practical economics, in order to develop an indicator that informs us not only about resource volumes but also about the amount of income (or utility) generated by the materials in question (section 6.1). We then look at how the indicators respond to the economic projections of the national Office of Economic Policy Analysis, CPB (section 6.2). Finally, we investigate how a major shift in the Dutch economy might impact on the indicators (section 6.3).

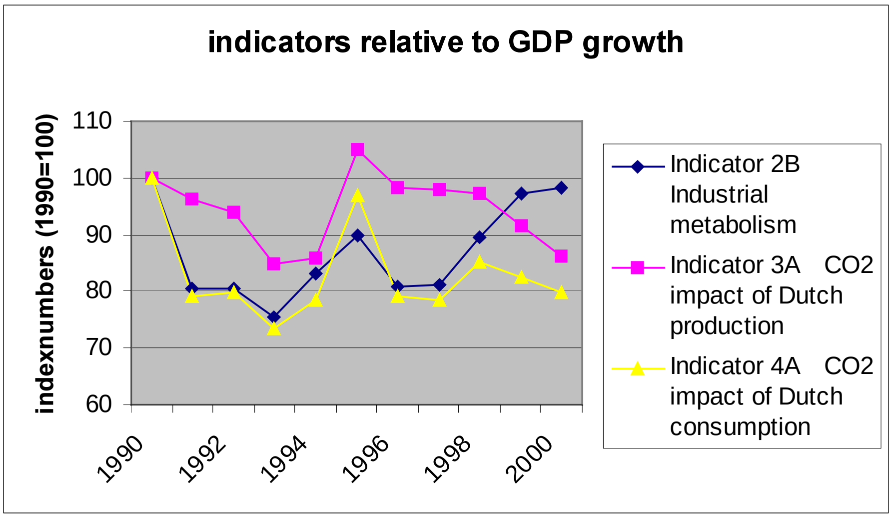
6.1 Indicators in relation to the economy

As argued in chapter 3, the principle aim of the envisaged dematerialisation indicator is to monitor the resource efficiency of the Dutch economy. Equipped with a set of absolute figures for dematerialisation, the question now is to what they should be related. In terms of the basic equation introduced in section 2.2, what is to be taken as the denominator? There are two options available.

The first is to express resource consumption as a function of Gross Domestic Product, an approach that is widely adopted. If GDP is taken as a proxy for economic welfare, the dematerialisation indicator then expresses the welfare generated by these resource flows in their passage through the Dutch economy.

The following figure shows trends in the three selected indicators relative to GDP growth.

Figure 15 Trends in the selected indicators relative to GDP growth



All three indicators were lower per unit GDP in 2000 than in 1999. The curve of indicator 2B, for industrial metabolism, is remarkably U-shaped. Since 1996 this indicator has risen substantially, by about 20%. The Dutch economy, in other words, was some 20% less resource-efficient in 2000 than four years earlier.

Up to 1998 the CO_2-weighted indicator for Dutch consumption (4A) follows indicator 2B fairly closely, but after that the two are delinked.

The figure also shows that since 1995 the contribution of dematerialisation to meeting the Kyoto commitments (indicator 3A) has become relatively delinked from GDP. In other words, the greenhouse emissions associated with domestic materials production have not grown by as much as the economy.

A second option for a denominator for the dematerialisation indicator is the economic utility derived from the materials in question. This begs the question of how utility is to be measured. The simplest approach is to assume that the price paid for materials reflects their perceived utility. After all, a material deemed useless will not be purchased. The total utility derived from these ten materials can thus be calculated by summing price times volume for each, or in other words the aggregate economic turnover generated with these materials. This is *de facto* the total amount of money a society is prepared to pay for using the materials concerned.

The results for the three indicators in this second approach are shown below in the figure[33]. The most striking thing now is the pronounced downturn in the year 2000. This can be explained by the steep rises in raw materials prices that year. Up to then the indicator curves are more or less U-shaped, with a trough between 1994 and 1996.

One consequence of calculating dematerialisation in this way is that with rising prices and volumes unchanged there is still dematerialisation. Although there may be intuitive resistance to this notion, it can also be argued that higher resource prices generally herald a decline in resource consumption: because of falling demand and substitution effects, sooner or later a higher price will translate to a reduction in demand volume[34]. Another consideration here is that higher resource prices may in themselves be an implicit aim of dematerialisation policy, and this indicator makes this aim explicit.

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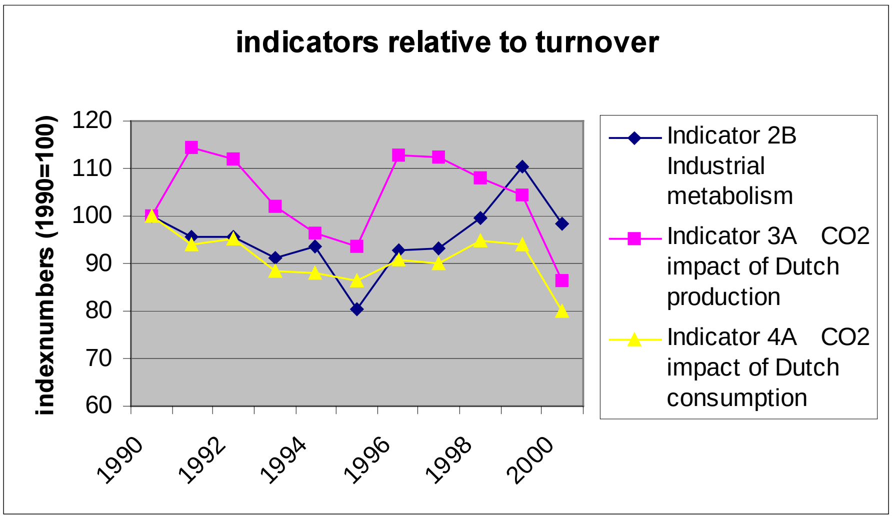
33 Price data are given in Annex D.

34 A more extensive analysis of the relationship between price and demand volume on raw materials markets is provided in Box C1 of Annex C.

Figure 16 Trends in the selected indicators relative to economic turnover



6.2 Trends to 2010

We can also examine how these indicators would be affected by major shifts in the Dutch economy. To this end we first assess indicator trends up to the year 2010, using the projections for economic growth developed by the national Office of Economic Policy Analysis, CPB.

In 1997 CPB estimated the physical output of the Dutch economy – as tonnes of steel, aluminium and so on – and concluded that output had grown by less than GDP over the period investigated (CPB, 1997). In their analysis, a combination of dematerialisation and structural adjustment (shift to a service economy) was leading to a declining share of materials production in GDP.

CPB employ fairly high estimates for both dematerialisation and structural adjustment. On average over the decade, dematerialisation is assumed to slow down growth in resource consumption by 1 percentage point relative to GDP growth, with structural effects possibly giving about 0.5% additional savings. In the CPB analysis, then, the two effects are together estimated to lead to about 1.5% less overall growth in materials consumption than in GDP. Not surprisingly, this result is a source of controversy. De Bruyn & Opschoor (1997), for example, have noted that in the absence of major price hikes in the raw materials markets a 1-to-1 relationship is more likely[35]. The analysis of section 5.1, above, also indicates that the indicators based on materials *tonnage* have grown virtually in step with GDP.

If the CPB projections of around 1.5% materials savings per annum through to 2010 are to be borne out, then, there will have to be a major breach of past trends. This noted, though, in order to make our calculations more manageable we here take the CPB figures at face value and assume there will indeed soon be some kind of break in current trends, whether or not induced by instigation of a *dematerialisation policy* in the Netherlands.

The following table shows the growth figures used by CPB in their 'EC scenario', a mid-range scenario with 2.75% average annual economic growth up

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35 The arguments are elaborated in De Bruyn (2000), chapters 2 and 8.

to the year 2010, or 31% over the entire decade. Note that this figure is fairly similar to the real GDP-growth in the 1990s.

Table 6 Percentage annual growth of physical flows in the Dutch economy by CPB sector, showing materials included in the pilot dematerialisation indicators developed in this study

CPB sector	Materials	GDP production	Physical production
Crude Steel	Crude Steel	1.6	0.4
Non-ferro	Aluminium, copper	1.5	0.5
Petrochemicals	Naphtha	2.7	2
Inorganic	Chlorine	3	2.25
Paper	Paper & cardboard	1.75	1
Construction materials	Wood, sand, cement	1.5	1
Food / Agriculture	Soybeans	2.2	0.9

NB: Figures for soybeans are our estimates, based on CPB (1997).

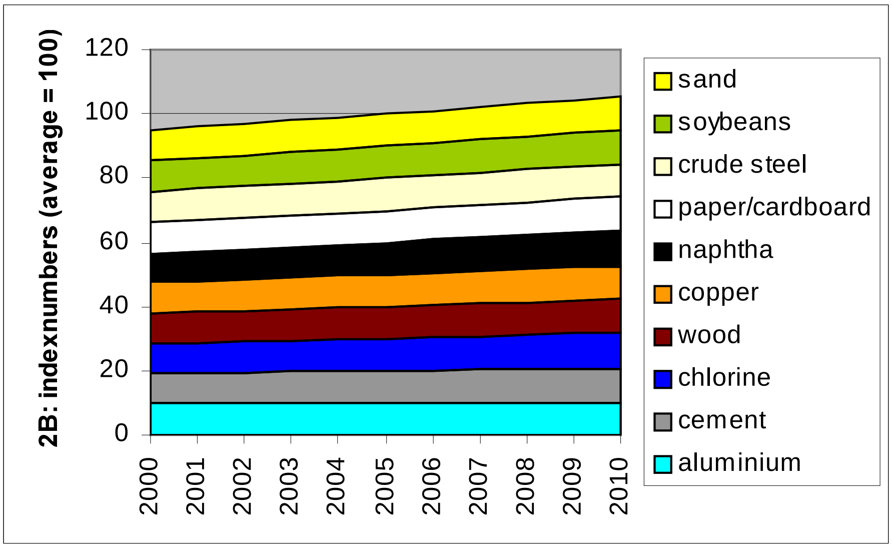
Using these growth data we computed trends in the three indicators of interest up to the year 2010. We thereby made the simplifying assumption that the ratio of production to consumption remains unchanged; in other words these growth figures are indicative of trends in both materials production and consumption[36].

For the respective indicators the following, linear trends were obtained through to 2010:

1 Between 2000 and 2010 the industrial metabolism indicator (statistically weighted) rises by 11%, far less than overall economic growth (31%). This is a result of the trend break assumed by CPB, as already discussed; between 1990 and 2000 this indicator actually grew at the same rate as GDP.

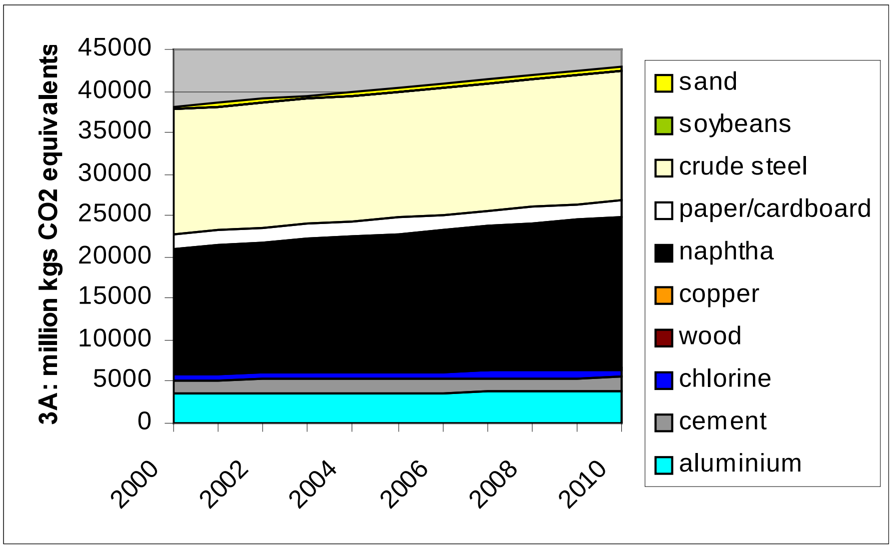
[36] In reality, of course, CPB does not make such an presumption and with a little effort and a few assumptions the difference between consumption and production can also be derived from the CPB data, but this is not our aim here – which is to illustrate the response of the indicator – and would complicate matters unnecessarily.

Figure 17 Indicator 2B: Industrial metabolism, statistically weighted



2 The indicator for the CO_2 impact of production rises slightly faster: by 12% over the same period. Apparently, domestic production of materials with high CO_2 emissions is anticipated to grow more than projected growth of domestic materials consumption[37]. Here we can observe how the relative share of aluminium declines, yielding ground to naphtha in particular.

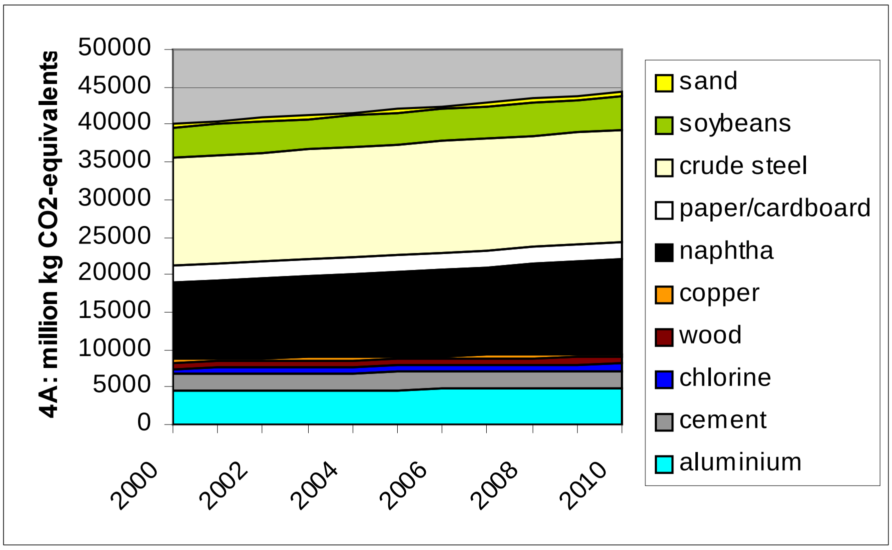
Figure 18 Indicator 3A: CO_2 impact of Dutch production



3 The indicator for the CO_2 impact of consumption, finally, increases by a little over 10%. The gentler upward slope of this figure is due to the modest growth of soybeans, an important element of this indicator.

[37] It should again be stressed that in our analysis production and consumption have been assumed to grow at the same rate, which CPB do not.

Figure 19 Indicator 4A: CO_2 impact of Dutch consumption



Additional analysis showed that all the other indicators give a similar picture, all of them rising over the decade by between 9 and 15%, depending on the particular mathematics of the indicator.

6.3 Scenario analyses

To illustrate some of the practical uses to which the indicators might be put, we now examine how the pilot indicators would respond to major shifts in Dutch production and consumption patterns, thus to provide insight into how changes in the economy and in human preferences are registered.

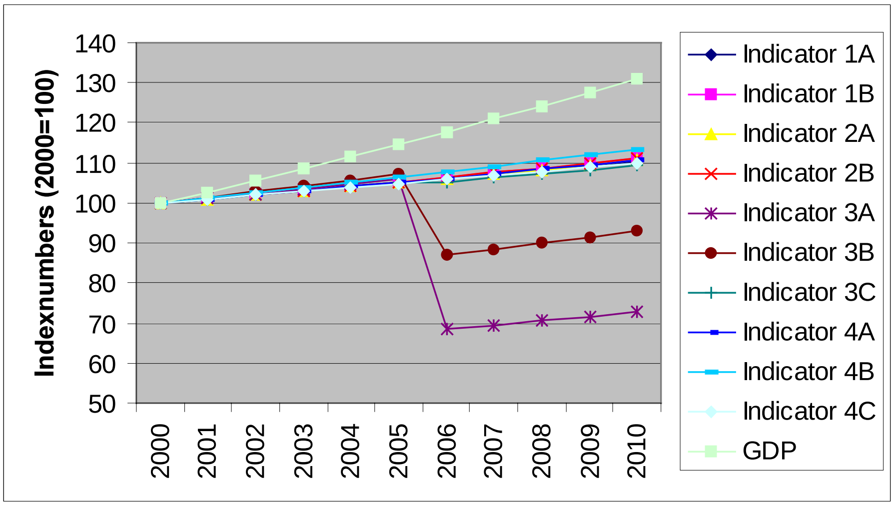
To this end we consider two hypothetical questions:

1. What would happen if an entire industry were relocated abroad?
2. What would happen in the event of pronounced demand-side shifts?

6.3.1 Foreign relocation of basic industries

Transferring basic materials production abroad should not affect the value of a dematerialisation indicator designed to monitor resource efficiency, which should be impervious to the issue of where materials are sourced. By way of illustration, the following figure shows the consequences of relocating Dutch steel production abroad.

Figure 20 Impact of relocating Dutch steel production



As can be seen, relocating production does not affect the consumption-based indicators, i.e. indicators 1, 2 and 4 (and their variants). It is only indicators 3A (-27%) and 3B (-9%) that exhibit any marked decline, because of the CO_2 emissions and final waste associated with primary steel production. If the aim of dematerialisation is to monitor resource efficiency, though, these do not serve as useful indicators[38].

6.3.2 Demand-side shifts

To assess the effect of demand-side shifts on the various indicators we ran a scenario to estimate the consequences of a temporary stoppage of all construction activity in the Netherlands in 2010. The precise calculations can be found in the Annexes (available in Dutch only).

Discontinuation of construction would affect a multitude of materials, having a major impact on five of the materials considered in this study, viz. sand, cement, aluminium, steel and copper. The impacts on the use of chlorine (PVC pipes) and wood (window-frames, doors, etc.) were not assessed, as these were judged to be relatively minor.

For the five material flows cited we sought to establish the share consumed by the construction industry. A distinction was thereby made between the housing and utilities sector (which we shall refer to as H&U) and civil engineering (or CE), as our concern was to examine the impact of stopping construction in the H&U sector only.

Table 7 below shows total consumption of the five cited materials by the construction industry and the respective shares of the H&U and CE sectors.

[38] The land use indicator for materials production remains virtually unchanged (+9%), because the land-use impacts of steel production are relatively minor.

Table 7 Building industry consumption of the five materials of interest

	Share of construction	Of which attributable to	
	% of material flow	H&U	CE
Fill & perc sand	100%	40%	60%
Concrete sand	100%	70%	30%
Cement	100%	70%	30%
Aluminium	40 (+/- 5%)	40%	1-5%
Steel	32%	16% (assumed)	?
Copper	75%	75%	Low

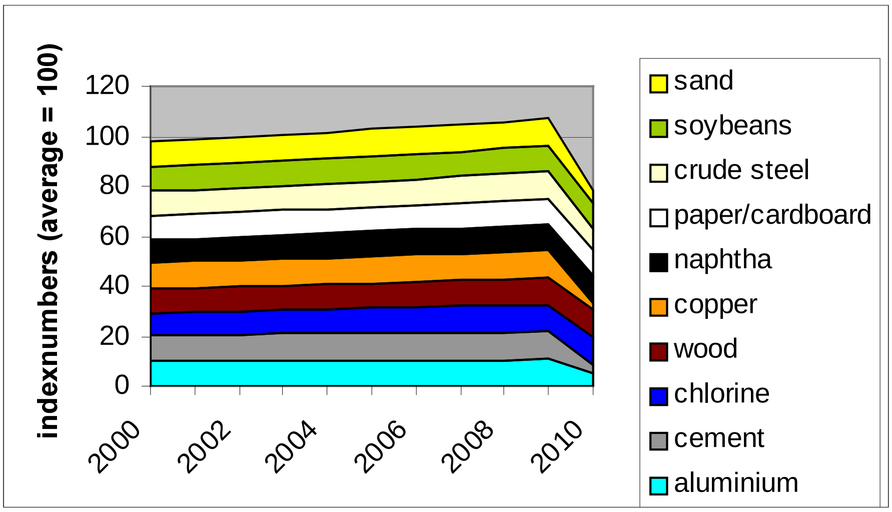
A construction stoppage would obviously impact on both production and consumption of the materials in question. We assumed the following:

1 Imports of sand and cement come to a halt.
2 Production of sand and cement match current export volumes. Given the bulk nature of these flows, we assume it will be hard to move into new markets.
3 Reduced domestic demand for aluminium, steel and copper is offset by higher exports: production of these materials thus remains unaffected by the construction stoppage.
4 The production to consumption ratio of both fill & perc and concrete sand remains the same as in 2000.

For the indicators of preference and interests this yields the following results:

1 Indicator 2B, for consumption-based industrial metabolism, falls sharply, by no less than 27% between 2009 and 2010. Even compared with the value in the year 2000 the indicator is almost 20% lower in 2010.

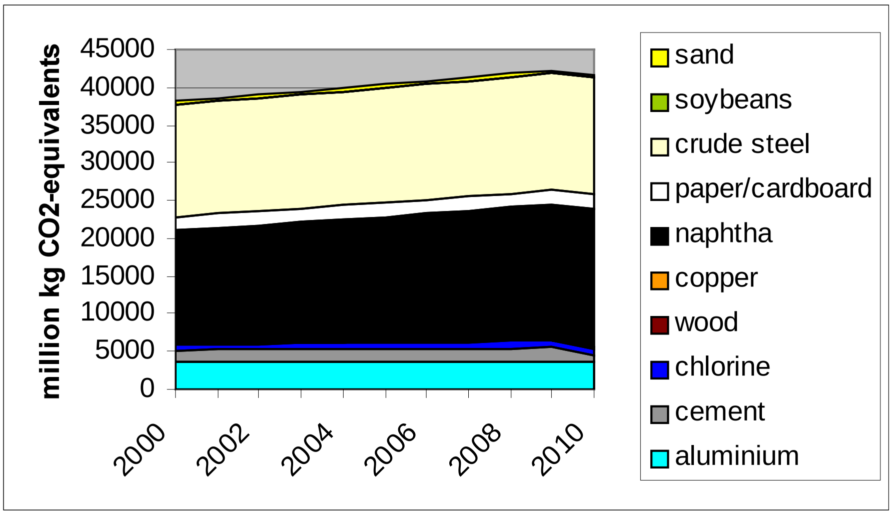
Figure 21 Impact of construction stoppage: Index 2B (industrial metabolism, statistically weighted)



2 Indicator 3A, reflecting the contribution of dematerialisation to meeting the Kyoto commitments decreases by less, however. In 2010 the value of the indicator is less than 2% lower than in 2009. All in all this indicator still increases by almost 9% between 2000 and 2010. This modest influence on production is due to the assumption that a construction stop-

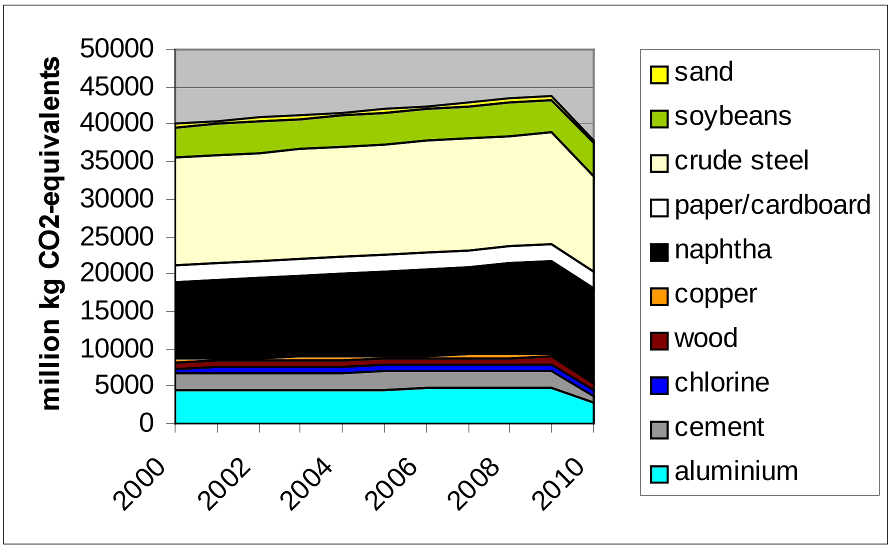
page would only affect production of bulk materials like sand and cement, responsible for a minor fraction of the CO_2 emissions associated with Dutch materials production.

Figure 22 Impact of construction stoppage: Indicator 3A (contribution to environmental policy: CO_2)



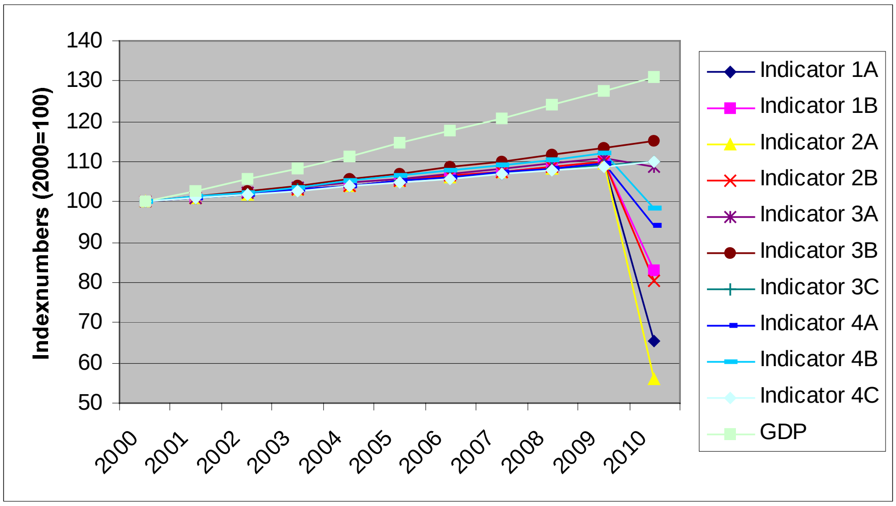
3 The effect on the CO_2 impact of Dutch consumption (indicator 4A) is greater. In 2010 this indicator is down by 14% compared with the previous year. Compared with 2000 there is an overall reduction of a little under 6%. It is noteworthy that this CO_2 indicator is affected less than the statistically weighted indicator based on materials mass (indicator 2B).

Figure 23 Impact of construction stoppage: Indicator 4A (CO_2 impact of Dutch consumption)



The following figure reviews the impact of a construction stoppage on the other indicators. As can be seen, the indicators for land use remain unaffected by such a step. Quite logically, the drop in value is greatest for indicators based on raw materials *tonnage*, such as 1A and 2A, where sand predominates, moreover. The dematerialisation registered by the indicators declines significantly if flows are weighted according to environmental impact. The production-related indicators register least dematerialisation.

Figure 24 Impact of construction stoppage: all indicators



7 Conclusions and recommendations

7.1 Defining the policy setting

Dematerialisation has a possible role to play in reducing the environmental impact of materials usage in the Dutch economy. Although for a long time the topic was studied and discussed mainly by academics, dematerialisation is now interesting politicians and policy-makers, who want to know whether it can support environmental policy. This study has examined the possible contours of such policy on dematerialisation and the implications for the choice of one or more indicators to measure it.

The Netherlands' 4th National Environmental Policy Plan (NEPP4) announces the intention to instigate a policy on dematerialisation. This document casts dematerialisation mainly in the role of complementary environmental policy, on the grounds that policies geared specifically to reducing a given environmental impact are far more effective than simply choking off entire flows of material resources. In discussions with policy officials in conjunction with this project it transpired that the envisaged role of dematerialisation policy within the overall environmental policy framework can best be understood by analogy to energy policy.

Dutch energy policy, with concerns extending beyond the environment, seeks to reduce the environment burden associated with energy use by way of four main strategies:
- substitution of fossil fuels for renewable energy sources;
- use of cleaner (e.g. low-carbon) fossil energy sources;
- use of process-integrated and end-of-pipe technologies to reduce emissions;
- improvement of energy efficiency (energy saving).

The aim of materials policy is to reduce the environmental burden associated with materials consumption. Although Dutch policy in this area is presently less coherent than in the case of energy, the available strategies are similar:
- application of recycling and other forms of reuse and use of renewable materials (sustainable resource use);
- use of environmentally more benign materials (product policy);
- reduction of material-specific emissions (integrated product management);
- improvement of materials efficiency (dematerialisation).

While the first three of these resource strategies are already embodied fairly consistently in standing policy, a strategy for directly improving the efficiency of resource use is lacking. Although this observation says nothing about the actual need for dematerialisation policy, a complementary role for such policy might be sought in this specific area. The goal of dematerialisation policy would then be to reduce environmental burdens further by improving the efficiency with which materials are used in the economy, or in other words to improve materials productivity.

7.2 Constructing a dematerialisation indicator

Delineating a dematerialisation policy in this fashion has implications for the criteria to be met by an indicator to monitor it. While the traditional dematerialisation literature has focused mainly on reducing aggregate material *inputs* to the national economy (as with the Total Material Requirement (TMR) and Direct Material Input (DMI) indicators), a dematerialisation indicator designed from the perspective of resource efficiency should focus on materials *consumption*. Such an indicator should, moreover, be developed in the understanding that it is not so much the materials themselves that are the problem but the environmental burden associated with extraction, processing, transportation and use.

From this perspective, a dematerialisation indicator can be defined as a numerical parameter representing trends in the aggregated consumption of selected material flows relative to the economic utility derived from those flows. It should reflect as closely as possible the environmental burden associated with consumption of the materials in question.

Before a dematerialisation indicator can be constructed a number of basic preliminary choices must be made. Principal among these are the following:

1 Choice of resources: which resource flows are to be included in the indicator? Is energy to be included or not?
2 Where in the material supply chain is consumption to be measured?
3 How are these material flows to be aggregated? By mass (as is common in the literature) or using other options such as weighting by environmental impact?
4 Are recycling and reuse to be taken as leading to dematerialisation or as 'material-neutral?

Based on a range of substantive arguments, and construction of ten pilot indicators based on a set of ten key material flows in the Netherlands[39], we have endeavoured to answer these questions. We summarise our results below.

1 Choice of resources

The designated policy setting means that the main focus of dematerialisation policy should be on materials for which no efficiency policy is currently in place. In practical terms, the indicator should thus encompass precisely these materials and no more. Given the existence of a solid energy policy, it is therefore inappropriate to include fossil fuels in a dematerialisation indicator. An exception will have to be made, though, for the use of fossil resources to produce materials like plastics not covered by agreements on energy efficiency.

An additional goal of dematerialisation policy is to reduce the environmental impact of resource consumption. It would therefore seem sensible to limit the scope of the indicator to those materials with substantial environmental impacts in the production, use and final waste phases of the life cycle. These impacts were assessed by considering the volume of the material flows in conjunction with their estimated impact.

[39] Specifically: naphtha, steel, aluminium, copper, wood, paper/cardboard, cement, sand, chlorine and soybeans, using data for the period 1990-2000.

2 Where in the supply chain is consumption to be measured?

The materials supply chain comprises a great many links as minerals and other resources are processed to final products and ultimately disposed of. A dematerialisation indicator that monitors the efficiency with which material resources are processed in the economy will have to focus on materials consumption. Although the ideal approach would be to measure the consumption embodied in final products, the data problems associated with such a vast range of articles are virtually insurmountable. A decision must therefore be made on where in the supply chain to measure the material flow and establish a figure for consumption.

According to NEPP4 the dematerialisation indicator should relate principally to the level of basic products and materials like metals, wood, foodstuffs, water, plastics, construction materials and metals. We explored this conception by analysing the scope for an indicator with reference to the experience already gained with energy indicators. In principle, a dematerialisation indicator could equally well be measured at a different level, for example that of raw materials, i.e. mineral ores and crude resources. An analysis of the total consumption of raw materials yields a different picture from total consumption of what we have here termed basic materials. In the first case the focus is on the material productivity of basic industries, in the second on the that of the consumer products and machine-building industries.

Which level is ultimately opted for in monitoring dematerialisation will be determined in part by the respective environmental gains anticipated. We expect these gains to be greatest, *a priori*, in the consumer products and machine-building industries, because it is precisely here that there is greatest scope for materials substitution as well as efficiency improvement: products can be manufactured using all kinds of materials, each with their own environmental profile. Upstream in the basic metals industry such substitution is scarcely feasible, if at all. This underlines the importance of basic materials in the analysis of dematerialisation.

3 Aggregation of material flows and their environmental impacts

Although most dematerialisation studies have aggregated material flows on the basis of tonnage, an analysis of ten key flows in the Dutch economy shows that in this country weighting by mass would yield a dematerialisation indicator steered almost entirely by trends in the consumption of sand. It would then suffice to simply monitor a couple of bulk flows like sand and gravel, which are of little relevance from an environmental perspective.

The alternative is to apply a more sophisticated weighting procedure. In this project we tested two methods: a simple form of statistical weighting and weighting according to the environmental impact of materials use in terms of climate change (emissions of CO_2-equivalents), final waste and land use. In doing so we opted to include impacts arising over the full length of the supply chain, ‘from cradle to grave’, because materials consumption in the Netherlands leads to significant environmental impacts in other countries, too, during mining and extraction, for example. These impacts can be quantified by means of Life Cycle Assessment.

Using the results of LCA studies it proved relatively easy to derive figures for the climate change impact associated with consumption of the materials of interest. In the case of final waste impacts, there were several problems regarding how ‘final waste’ should be defined – whether or not it should include mining spoil, for example – which may have a major effect on results. A key issue here is that the ultimate environmental impact of waste materials is not always determined by their volume. Mining spoil returned to a mine has far less impact than toxic waste released anywhere, for instance, and there is no satisfactory way to compare the two. These kind of 'quality' issues are even more important in the case of land use, which is usually expressed simply as square metres. The various forms of land use represent an enormously wide spectrum of environmental quality, however, with open-cast mining obviously having a far greater impact than productive woodland. As yet we see no satisfactory way of doing justice to these various quality differences in a dematerialisation indicator.

One alternative is to weight materials throughput statistically. The indicator resulting from the simple form of statistical weighting applied in this study showed a high degree of correlation with the final waste indicator and might therefore serve as a substitute for a general environmental indicator.

4 Recycling and reuse

The best way to incorporate recycled and reprocessed materials in the indicator is to weight their flows according to the environmental burden associated with the recycling process. This can guide decisions on what makes most environmental sense: to cut back consumption of a given primary material, substitute recyclate, or substitute another material altogether. This would argue for an indicator based on environmental weighting of material flows.

On the other hand, our pilot indicators show that it makes little difference to indicator trends whether or not recycling is included, for most recycling percentages stayed fairly constant throughout the '90s. If the prime aim of a dematerialisation indicator is not to measure aggregate throughput but *changes* in that throughput, then recycling and reuse may not be that important elements of an indicator. If the indicator is to be used to make *comparisons between countries*, however, it may well be useful to include recycling because of the marked differences between national recycling percentages.

7.3 Recommendations

Besides proposing a policy framework for dematerialisation and constructing a set of pilot indicators, this project yielded the following results:

1 The best indicator(s)

Two indicators were identified as being most promising for monitoring the effectiveness of any government policy on dematerialisation:

A An indicator measuring consumption of basic materials, with recycling taken as a form of dematerialisation and material flows statistically weighted (*indicator 2B, Figure 7)*.

B An indicator measuring consumption of basic materials, with both primary and secondary material flows weighted by greenhouse emissions *(indicator 4A, Figure 11)*.

Among the various indicators developed, these two best satisfy the aforementioned criteria: both provide a sufficiently comprehensive snapshot of (progress on) dematerialisation, understood as improved materials efficiency with probable environmental gains. These indicators still need to be augmented by additional material flows, however. There is also scope for improved assessment of environmental impacts as well as statistical weighting methods, the latter using factor analysis, for example.

Which of the two indicators is eventually chosen depends on the designated goal of dematerialisation policy. If policy-makers wish to weight materials consumption for 'climate impact', the second indicator is the obvious choice. If another policy focus is adopted, the first is probably more appropriate.

Simple aggregation according to mass, common practice in many studies, was found ultimately to say very little about the environmental burden attributable to material flows.

2 *The results of this study call into doubt the wisdom of current European focus on the dematerialisation indicators DMI en TMR*

In our view the indicators DMI (Direct Material Input) and TMR (Total Material Requirement), currently the main focus of European policy efforts (see Mathews, 2000 and Moll *et al*., 2002), are less suitable for monitoring dematerialisation policy, for three main reasons.

First, they measure material *inputs* to the economy. This kind of indicator is unsuitable for pronouncing on the efficiency of materials use, because materials input says little if anything about materials *consumption*. In the specific case of the Netherlands this is doubly important, because here DMI and TMR are both large compared with domestic materials consumption. The prominent role of both basic industries and the transit trade in the Dutch economy means that imports of fossil fuels and mineral ores are relatively high, although these are largely re-exported in crude or processed form (e.g. naphtha for plastics production, metals). The Direct Material Consumption calculated by Moll *et al.* (2002) is perhaps better suited to this purpose, because this indicator informs about consumption.

Second, these indicators aggregate flows according to *mass*, destroying any meaningful correlation with the environmental burden of the individual materials in question. Our study shows that the main upshot is that the indicator is dominated by environmentally irrelevant materials.

Third and last, fossil fuel flows feature relatively prominently in trend analyses using DMI and TMR. To our mind, it is better to address these flows via energy policy rather than materials policy.

3 *The sharp rise in materials consumption observed points to the need for a policy on dematerialisation*

A second-order conclusion of this study, as revealed in the trend analyses using the pilot indicators, is that dematerialisation policy should indeed be instigated. All the variant indicators examined point to a substantial increase in Dutch materials consumption during the 1990s, with some figures even exceeding GDP growth. In our estimate, economic consumption of the ten major bulk materials selected, analysed 'from cradle to grave', is responsible for about 15% of national emissions of CO_2-equivalents, approximately twice the projection of the government's 4th National Environmental Policy Programme. The growth in materials consumption is proof that this source is not being satisfactorily addressed by standing policy.

In 1997, moreover, the national Office of Economic Policy Analysis (CPB), predicted a major trend towards dematerialisation in the years ahead. It is on these projections that the benchmark *National Environmental Outlook* reports of the National Institute of Public Health and Environmental Protection (RIVM) are based. To date, however, no such trend can be observed. Between 1996 en 2000, particularly, materials consumption in the Netherlands frequently outstripped economic growth, in fact, with precise results depending on which indicator is chosen. Over the decade from 1990 to 2000 the ten dematerialisation indicators increased overall by 24% on average, compared with 33% aggregate economic growth over the same period.

This study indicates that if a dematerialisation policy is indeed implemented, it will have to be fairly sophisticated, not a crude variant based merely on tonnages. Given the results obtained here, this seems well feasible. Additional research will be needed to translate the pilot indicators to conversion or efficiency ratios for specific industries, for possible use in long-term agreements on specific sectoral performance, for example, or in corporate environmental programmes.

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Trade associations
- AVIH, Algemene Vereniging Inlands Hout
- CEPI, Confederation of European Paper Industries
- EAA, European Aluminium Association (Bas Lambrechtsen)
- Eurochor, European trade association of chlorine producers (Griet Provoost 00 32 2 26767252)
- IISI, International Iron and Steel Institute
- Staatsbosbeheer (Dutch Forestry Commission)
- Stichting Aluminium Centrum (Niels Ruyter)
- Stichting Bos en Hout
- VNP, Vereniging Nederlandse Papierfabricanten
- VNC, Vereniging Nederlandse Cementindustrie
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Overview datasources used for database

The following two tables give an overview of the sources we have used for constructing the database for 10 material flows in the Netherlands.

Table 8 Overview datasources production and trade flows

	Production	**Import**	**Export**	**Re-use and recycling**
Naphtha	IEA 2001	IEA 2001	IEA 2001	nvt
Steel	Corus/Nedstaal	ICTS	ICTS	Corus/ Nedstaal
Aluminium	US Government commodity statistics	ICTS	ICTS	Stichting Aluminium Centrum
Copper	CBS	ICTS	ICTS	CE
Paper, cardboard	FAO database VNP en CEPI	ICTS	ICTS	VNP
Wood	AVIH	ICTS	ICTS	NA
Cement	ENCI	ICTS	ICTS	NA
Sand	SOD/ DWW	SOD/ DWW	SOD/ DWW	SOD/ DWW
Chlorium	Eurochlor (not 1996, 2001)	CBS	CBS	NA
Soybeans	CBS	ICTS	ICTS	NA

Table 9 Overview sources environmental data

	Climate change	**final waste**	**landuse**
Naphtha	Apme 1999	Apme 1999	IVAM
Steel	Simapro (Buwal 1996)	SimaPro (Buwal 1996)	IVAM
Aluminium	EAA 2000	EAA 2000	IVAM
Copper	CE copper study	CE estimates	IVAM
Paper, cardboard	SimaPro (Buwal 250 1996)	SimaPro (Buwal 250 1996)	IVAM
Wood	SimaPro (Buwal 250 1996)	SimaPro (Buwal 250 1996)	IVAM
Cement	IVAM (VNC 1995)	IVAM (VNC 1995)	IVAM
Sand	IVAM (DIK betondatabase	IVAM (DIK betondatabase	IVAM
Chlorium	Simapro (Spin 1993)	Simapro (Spin 1993)	IVAM
Soybeans	IVAM	IVAM	IVAM