Environmental Life Cycle Assessment of Linoleum

- final report -

M. Gorree
J.B. Guinée
G. Huppes
L. van Oers

Centre of Environmental Science – Leiden University (CML-UL)

Leiden, June 2000

Research commissioned by Forbo-Krommenie B.V.

Content

Summary

Introduction

Forbo-Krommenie B.V. commissioned the Centre of Environmental Science (CML) to carry out an Environmental Life Cycle Assessment (LCA) with the purpose of assessing the environmental performance of linoleum floors, indicating possible options for improvement, and assessing the sensitivity of the results to methodical choices. The method followed in this study is based on Guinée *et al.* (2000) an update of the CML guide on LCA from Heijungs *et al.* (1992).

Goal and scope

The goal of this LCA study was to gain insight into:

- The environmental impact of Linoleum floor coverings.
- The effects of the different processes in the life cycle chain on the environmental impact of linoleum.
- Identifying possible improvements,
- The effects of choices in methods and data on the outcomes.

The following functional unit was used as a basis for this study:

2000 m^2 linoleum (produced by Forbo-Krommenie B.V. in 1998) used in an office or public building over a period of 20 years.

Three different functional equivalent alternative systems were considered:

- The baseline system: The production, laying, use and maintenance of 2000 m^2 2.5 mm Marmoleum®, in an office or public building in the Netherlands, over a period of 20 years and its subsequent disposal.
- The Swedish system: The production, laying, use and maintenance of 2000 m^2 2.0 mm Marmoleum®, in an office or public building in Sweden, over a period of 20 years and its subsequent disposal.
- The Corklinoleum system: The production, laying, use and maintenance of 2000 m^2 4.5 mm Corklinoleum, in an office or public building in the Netherlands, over a period of 20 years and its subsequent disposal.

Besides these various systems, a number of scenarios were examined with the purpose of providing a sensitivity analysis.

Inventory and impact assessement

The inventory and impact assessment were carried out conform a nearly final draft version of Guineé *et al.* (2000), an update of the LCA-guide by Heijungs *et al.* (1992) . This update follows the ISO standards as closely as possible, providing an operational outline of the theoretical starting points, requirements and guidelines given in the different ISO documents on LCA (ISO 14040, 14041, 14042 & 14043), as known to the authors when writing this report (December 1999). Some deviations from ISO standards have also been made mainly concerning the form of reporting.

<u>Data gaps</u>

No process data was available for the following processes:

- The production and transport of pesticides (use and emission of pesticides is included).
- The production and transport of some raw materials needed for maintenance products (additives, thickeners, solvents) and almost all ingredients for those materials.
- The production and transport of some raw materials needed for the production of materials used during laying (adhesives and materials used to seal the seams of professionally used linoleum floors)
- The production and transport of a catalyst needed in the process “esterification of tall oil “.
- The production and transport of the fertiliser S needed in the process “growing linseed “ .

- The production and transport of the maintenance product used for removing the polymer dressing of linoleum floor covering needed in the process “the use and maintenance of 1m2 linoleum for 20 years “.

Impact categories

The following impact categories are included in this study:

- Extraction of abiotic resources
- Climate change
- Depletion of the ozone layer
- Human toxicity
- Eco-toxicity
- subcategory: aquatic eco-toxicity
- subcategory: terrestrial eco-toxicity
- subcategory: sediment eco-toxicity
- Photo-oxidant formation
- Acidification
- Eutrophication
- odour

Besides the impact assessment method described in Guinée *et al.* (2000), a few other impact assessment methods were applied to determine the extent to which the results of the study are influenced by the method of impact assessment used.

Flows not assigned to an impact category

In total there were 264 inputs/outputs that could not be assigned to an impact category. These are mainly from the ETH database. A large portion of the emissions (132 emissions) are radioactive emissions. Since radiation is not included in this study (because no consensus has yet been reached concerning the impact assessment method to be used) it could not be included in the impact assessment results.

Interpretation and conclusions

Main contributing processes

The processes or groups of processes that contribute largely to more than one impact category are:

- The growing of linseed (emissions of NH_3, N_20 , pesticides).
- Gas and electricity used at Forbo-Krommenie B.V.
- Oil used for the production of maintenance products.
- The transport of raw materials.
- The incineration of linoleum.
- Coal used for the production of detergents and acrylic dispersions/emulsions.

Scenarios

The following conclusions were drawn from the scenarios:

- Extra transport by freighter to the USA has less impact than was expected.
- The influence of maintenance in the “use “ phase is not negligible as is often thought.
- The influence of other pigments than TiO2 can be considerable. TiO2 is not representative for other pigments. The impact of other pigments may be high even though their mass share in the product is much lower.
- Using tall oil in linoleum is better for the environment than using only linseed oil.
- Using 2.0 mm linoleum is better for the environment. However, this is only the case if the life span of the 2.0 mm linoleum is more or less the same as for the 2.5 mm version.
- Substitution of useful heat produced during the incinerating of linoleum with avoided electricity use is the best of the studied alternatives.
- Reduction in the use of pesticide only effects terrestrial ecotoxicity, and not the other toxicity categories.
- Reduction in the use of N-fertiliser affects the results for global warming, eutrophication and acidification substantially.

- Reduction of the transportation distance for raw materials has some effect on aquatic and sediment ecotoxicity.
- Changes in the composition of the VOC emissions at Forbo-Krommenie B.V. have a considerable influence on the category "odour ". A better estimate of the composition of these emissions is necessary in order to assess the effects on "odour " and "depletion of the ozone layer " properly in an LCA on linoleum products.
- The influence of capital goods is certainly not negligible. According to a very rough scenario leaving out capital goods may lead to an underestimation of 1-10%. The influence of the missing chemicals could be even more substantial. According to a very rough scenario these data gaps may lead to an underestimation of 5-40%.

<u>Data quality and applicability</u>
The main conclusions following from the analysis of data quality are:
- The results of the study are applicable for analysis of the described systems only. This means that:
  - The results should not be used to compare the environmental performance of linoleum produced by Forbo-Krommenie B.V. to other products.
  - The results should not be used to compare systems with different capital goods because capital goods are not included.
  - The results should not be used to compare different maintenance systems because too much data on chemicals in maintenance products is missing.
- The results for "odour " and "depletion of the ozone layer " should be presented with some care as the unreliable VOC estimations at Forbo-Krommenie B.V. play an important role in these impact categories.

Discussion & final conclusions

<u>Main contributing processes</u>
In the stage "production of raw materials" the processes "growing of linseed" and "transport" are important processes. The data for this process depend largely on assumptions. If these assumptions are not realistic, this may have large influences on results. Therefore, it is advisable to try to ground these assumptions with better data. Still, Forbo-Krommenie B.V. could improve their environmental performance on many impact categories by using linseed that is cultivated with less fertiliser and less pesticides.

In the stage "production of linoleum " the energy used at Forbo-Krommenie B.V. is most important. We expect that this data is valid and reliable. Saving on the use of electricity and gas is therefore an opportunity for improvement.

In the stage "laying and use ", the coal and oil used during the production of maintenance products is important. Data on the production of maintenance products is not complete. The results of the comparison of the Dutch and Swedish scenario showed a heavy influence of the lack of data on the production of Swedish maintenance products. Therefore, no conclusions can be based on the comparison of these maintenance systems, other than that maintenance is not negligible. Better data on maintenance products is needed before more conclusions can be drawn on the influence of maintenance.

In the stage "disposal " the emissions produced during incineration are important. However, the figure of 100% incineration of used linoleum and the linoleum waste from Forbo-Krommenie B.V. is only an assumption. From the scenario analysis followed that substitution of useful heat produced during the incinerating of linoleum with avoided electricity use shows the best environmental profile of all studied alternatives for handling waste. Therefore incineration seems a better alternative than landfill. However, this result should be considered with some care, because for landfills average ETH-data was used. These are probably not very realistic for the landfill of linoleum.

<u>Composition of linoleum</u>
In the scenarios a number of variation in linoleum composition have been studied. This showed that:
- The sensitivity analysis showed that the contribution of pigments other than TiO_2 to all impact categories can be considerable. However the data on pigments could not be checked for quality.

Moreover, these data were not provided by the suppliers of the pigments and the representativeness of these data might be disputed. There is a great variety of possible pigments, but little available information concerning their environmental performance. A more detailed analysis on this point focusing on the pigments that are actually used by Forbo-Krommenie B.V., aimed at finding pigments that are the most environment-friendly could be valuable**.**

- The 2.0 mm gauge has a considerably better environmental performance than the 2.5 mm gauge. On average, the results for this gauge are 15% lower. If the life span of both floors is comparable, Forbo-Krommenie B.V. might consider producing relatively more 2.0 mm products as a means of improving their environmental performance.
- Linoleum with tall oil has a better environmental profile than linoleum without tall oil, because the use of linseed is lower.
- Compared to the baseline 2.5 mm linoleum cork linoleum produces better results in most categories, but performs considerably worse in the categories “abiotic depletion “ and “odour “. Were the gas use during drying and milling of cork-granulate reduced, it would improve the results for these categories.

<u>Data gaps</u>

The influence of capital goods is certainly not negligible. According to a very rough scenario leaving out capital goods may lead to an underestimation of 1-10%). The influence of the missing chemicals could be even more substantial. According to a very rough scenario these data gaps may lead to an underestimation of 5-40%). Therefore, the results should not be used to compare systems with different capital goods or different maintenance systems. The results of the study are applicable for analysis of the described systems only.

<u>VOC</u>

The result for “odour “ and “depletion of the ozone layer “ should be considered with some care, since the emissions of VOC from Forbo-Krommenie B.V., which play an important role in these impact categories, were not specified.

Improvement options & advice for further studies

<u>Improvement options</u>

- Forbo-Krommenie B.V. could improve their environmental performance on many impact categories by using linseed that is cultivated with less fertilisers and less pesticides. This seems a more promising option than reducing transportation distances for raw materials.
- Saving on the use of electricity and gas at Forbo-Krommenie B.V. is also an area for improvement.
- The pigments used can have a large influence on environmental performance. A more detailed analysis on this point, aimed at finding pigments, which are safest for the environment, could be valuable**.**
- The 2.0 mm gauge has a considerably better environmental performance than the 2.5 mm gauge. On an average, the results for this gauge are 15% lower. If the lifetime of both floors is comparable, Forbo-Krommenie B.V. might consider producing relatively more 2.0 mm products in order to improve their environmental performance.
- Linoleum with tall oil shows a better environmental profile than linoleum without tall oil. Therefore, a reduction in the amount of tall oil, in favour of linseed oil, is not advisable.
- Reducing gas use during the drying and milling of cork-granulate would improve the results for “abiotic depletion” and “odour “ for cork linoleum. For other categories cork linoleum already produces better results compared to baseline 2.5 mm linoleum.

<u>Advice for future studies on linoleum</u>

It is advisable to give the following topics extra attention in future studies on linoleum as the data on these topics is fragmented and its influence on the environmental profile of linoleum could be considerable:

- The production and use of maintenance products, especially the Swedish type.
- The production and use of pigments other than TiO2.
- Emissions of individual VOC at the site of Forbo-Krommenie B.V.

Critical review statement of LCA of linoleum floors

CML has performed a Life Cycle Assessment (LCA) of linoleum floors, commissioned by Forbo Krommenie B.V. The critical review has been performed in three phases, and two meetings have been held. The last review was to confirm that the comments in the second phase where taken into account.

The goal of the study has been to learn about the environmental impact of the Linoleum floor coverings and the different contributing processes, to identify possible improvements and to learn about effects of choices in methods and data on the outcome. The first part of the goal is definitely met, since the results show which processes that contribute significantly to the different environmental impacts. Out of the identified significant issues, improvement options are suggested. These can be studied further in improvement assessments. The effects of choices in methods and data are partly studied and concluded on.

The critical review has been performed in order to:

- check that the methodology is in compliance with international standards on LCA, ISO 14040-14043, and scientifically and technically valid
- give advice on the data sources used
- check that the report is transparent and consistent
- check that the interpretation and the conclusions drawn reflect the limitations identified and the goal of the study

<u>Compliance</u>
The study has been performed according to all main requirements of the ISO 14040, 14041, 14042 and 14043 standards. Requirements such as sensitivity analysis in order to check the chosen criteria for inclusion of inputs and outputs is rather detailed, and hardly ever possible to fulfil for each input and output! The impact assessment give often a result that is incomplete (e.g. for photo oxidant formation, toxicity and odour) more because of lack of data than on the deficiencies of the characterisation methods. Since conclusions are based on more robust impact categories, the uncertainty within these impact categories does not effect the conclusions.

<u>Data</u>
Site specific data have been used when available. There are data gaps in the study, but many of the gaps have by a sensitivity check been shown not to be of large importance for the main results. Important data gaps may be the pigments used, the maintenance products used (the production of these products) and the VOCs from the linoleum production and storage. Other data gaps are emissions from landfill and incineration of Linoleum.
Essential assumptions for data and data sources are documented in a transparent way in an annex. However, the inputs and outputs for each process is only documented in the LCA tool, which is not so easy to use, why the inventory calculations have not been checked.

<u>Methods</u>
The methodology used is presented in a clear way. Some deviations from ISO recommendations exist, e.g. for incineration and landfill, where the allocation used in the ETH database has been used instead of a methodology recommended by the ISO 14041. This seems to have a small contribution to the total results, however, why this probably does not influence the main results.

<u>Interpretation</u>
The interpretation has been done in accordance with the requirements of 14043, and in line with the goal and scope. The sensitivity analysis of e.g. the pesticide use show in an illustrative way how the uncertainty in amounts of pesticide and fertiliser effects the different impact categories. The conclusions are drawn in line with the goal and scope.
The conclusion is that the report can contribute to the increased knowledge of Forbo about the environmental impact of Linoleum floor covering, and that it is a good basis for further studies. The results can be communicated externally, since there is a third party report that shows how the study

has been performed. It should, however, be clear when results are communicated that the results can not be compared to results of other studies, since the choice of methodology, assumptions, system boundaries, data for e.g. electricity production etc often differ to a large extent.
At last the critical reviewer would like to thank for a good and constructive co-operation.

Elin Eriksson
CIT Ekologik, Stiftelsen CHALMERS INDUSTRITEKNIK
Göteborg, 2000-06-20

1 Introduction

1.1 General

Linoleum is a floor covering consisting of a binder made from linseed oil and/or vegetable drying oils and rosin mixed with wood flour and/or cork, inorganic filler and pigments, on a carrier of jute. Forbo-Krommenie B.V. is the world's largest producer of linoleum floor covering (Marmoleum®, Artoleum®, Corklinoleum and Walton) and of other linoleum products (Desk Top® and Bulletin Board®). The products are sold all over the world but principally in Western Europe and the USA. Forbo-Krommenie B.V. commissioned the Centre of Environmental Science (CML) to carry out an Environmental Life Cycle Assessment (LCA) in order to assess the environmental performance of linoleum floors, to indicate possible options for improvement, and to assess the sensitivity of the results in methodical choices.

Elin Eriksson, of Chalmers Industriteknik in Sweden carried out a peer review.

1.2 Environmental Life Cycle Assessment (LCA)

The LCA is defined by ISO as a "compilation and evaluation of the inputs and outputs and the potential environmental impacts of a product system throughout its life cycle " (ISO 14040, 1997). It is a method that is meant, based on a 'cradle-to-grave' approach, to systematically evaluate the environmental impacts of products and activities. This approach is based on the identification and quantification of the flows of substances and materials (or other interventions) to and from the economy and the environment, during the entire life cycle of the product or activity. Economy is defined here as all human activities that take place more or less isolated from the environment. In other publication, sometimes the word 'technosphere' is used to describe this concept. In Figure 1 the main methodological framework according to ISO is given.

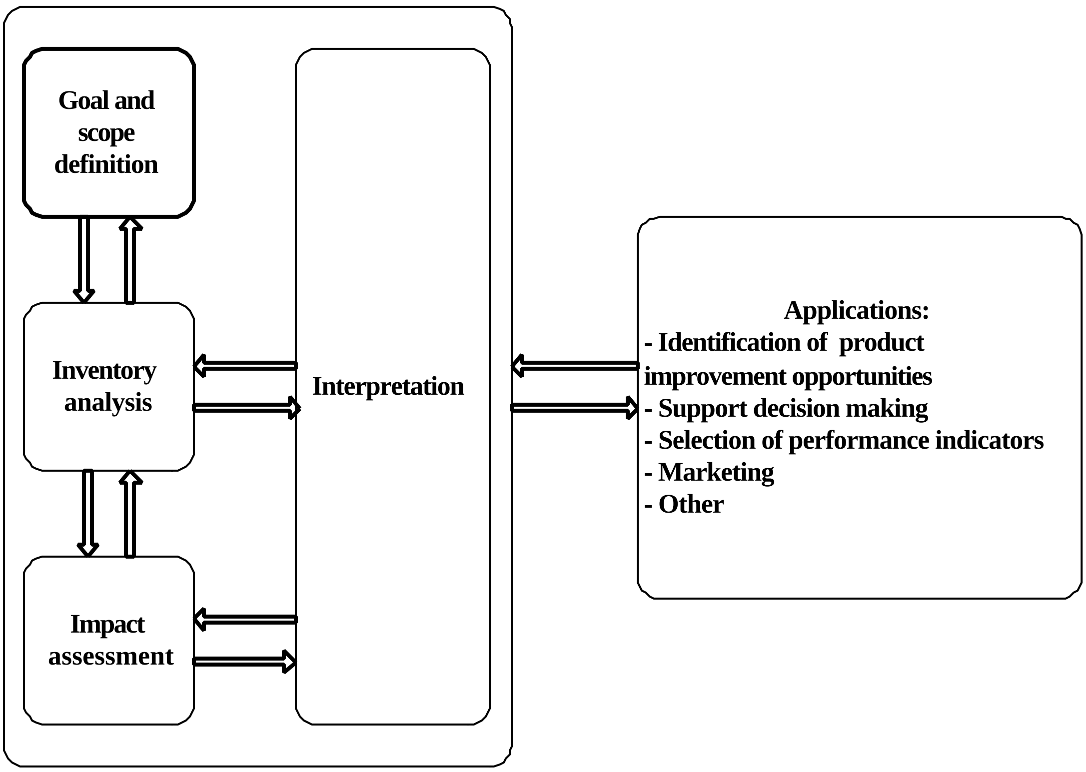


Figure 1: The general methodological framework for LCA (ISO 14040, 1997).

In ISO 14040, 14041, 14042 & 14043 requirements are stated for every phase of the LCA and even more technical reports and standards are in development. These ISO standards and guidelines are very important in providing an international reference on principles, framework and terminology for conducting and reporting LCA studies. The ISO standards, however, do not supply the reader with a "cookbook " outlining step-by-step operational guidelines for conducting a LCA study. ISO standards contain elements that shall or should be considered when conducting an LCA, and when communicating the results.

Currently, Guinée *et al.* (2000) are writing an update of the LCA-guide by Heijungs *et al.,* (1992). This update follows the ISO standards and guidelines as closely as possible, providing an operational outline of the theoretical starting points, requirements and guidelines given in the different ISO documents on LCA (ISO 14040, 14041, 14042 & 14043), as known to the authors at the moment of writing (December 1999). Guinée *et al.* (2000) take the Guide by Heijungs *et al.* (1992) as a starting point, and then further update this guide[1] by including all relevant developments which have taken place since its publication, with particular reference to the work taking place within the SETAC community. Some additions to ISO standards have been made in order to achieve operationalisation. Some deviations from ISO standards have also been made, but only if there were really significant arguments to do so. The main deviations concern the form of reporting. In Guineé *et al.* (2000) the guidelines for reporting are different for separate goal and scope studies (which is in line with ISO), and for final reports, in which the description and discussion of several topics is not placed in the goal and scope, but rather in later sections of the report closer to the topic itself (e.g. data quality, system boundaries etc.). Additions and deviations have all been documented comprehensively in the guide. The present study is based on the nearly final draft version of the updated guide (Guineé *et al.*, 2000).

[1] For a Guide on how to perform an LCA, we believe that it is important to structure the methodology in distinct steps which can be documented and reported separately in an LCA-report, and which follow a logic working plan. Iterations between steps are always possible and necessary, as LCA is an iterative technique, but iteration as such is not an individual step.

2 Goal of the study

In the goal definition of an LCA, besides the goal also the intended application, initiator, performer and intended audience should be stated according to ISO (ISO, 14040). In this chapter, these topics are described sequentially.

2.1 Goal definition

The goal of this LCA study is to gain insight into:

- The environmental impact of linoleum floor coverings.
- The effects of the different processes in the life cycle chain on the environmental impact of linoleum floor covering.
- Identifying possible improvements
- The effects of choices in methods and data on the outcomes.

2.2 Intended application of the study results

The results of this LCA will be used:

- For product and process development:
  Forbo-Krommenie B.V. wants to be able to analyse (with the aid of the delivered software) the effects of process changes in terms of technology, input and product composition on the total environmental impact. This information can, in turn, be used to prioritise different measures that may be taken to improve Forbo-Krommenie B.V.'s environmental performance.
- As a basis for answering questions received from business relations
- Possibly as basis for a brochure that serves marketing needs by communicating the environmental performance of Forbo-Krommenie B.V.'s products to external relations. Therefore, the requirements for third-party reports from ISO (ISO 14040, 14041 and 14042), including a critical peer review, are followed in the present report

The results of this study will not be directly applied to a comparison of Forbo-Krommenie B.V. products with floor coverings from other manufacturers (which would constitute a comparative assertion). Although this is the case, it is possible that they could be used as a basis for making comparative assertions in the future. In this case, however, additional requirements should be met (amongst others the ISO requirements for comparative assertion).

2.3 Initiator

The initiator and commissioner of this LCA study is Forbo-Krommenie B.V. in the Netherlands.

2.4 Performer

The performer of this LCA study is the Centre of Environmental Science, Section Substances and Products, Leiden University, Netherlands (CML).

2.5 Target audiences

The target groups for this study are Forbo-Krommenie B.V., its customers and other associates interested in the environmental performance of linoleum products.

3 Scope of the study

In this chapter, principal choices concerning the scope of the study are outlined. These include the breadth and depth of the study, functional units and functionally equivalent systems. These are described in § 3.1 to 3.4.

According to ISO, main choices and assumptions on the next phases of the LCA should be described under scope. These include choices and assumptions on system boundaries, data collection, applicability etc. However, Guinée *et al.* (2000) advise doing so only in the initial goal and scope description. In the description of a fully elaborated LCA, such assumptions should be treated, in as far as possible, where the topic itself is described in the report, since assumptions and choices often change during typically iterative LCA processes. In order to adhere as closely as possible to the ISO guidelines, we summarise the main assumptions and choices in § 3.5.

In § 3.6 finally the ISO guidelines concerning third party reporting and the need for a peer review are described.

3.1 Level of sophistication

An LCA can be performed so as to articulate a range of levels of sophistication. These levels are described in Guinée *et al.* (2000). For this linoleum LCA, a detailed LCA is carried out using default methods and sensitivity analysis on non-default methods. This is the operative level for a professional study, for a vast but not overly complex application. The ISO guidelines are followed as closely as possible (ISO 14040, 14042, 14042 & 14043), including the recommended sensitivity analysis.

3.2 Type of analysis: descriptive and change oriented

This LCA describes environmental burdens that may be attributed to (the use of) a certain amount of a product or service (= descriptive) but also focuses on arguments to improve technologies and production processes (change oriented). This LCA should, therefore, be considered as a change oriented LCA rather than as a descriptive one. One of the main requirements of a change oriented LCA is that the processes included should be up to date so, that a fair comparison may be made between a system with “old “ processes and a changed system with improved processes, both based on recent data. In this study we used the most recent data available, mainly from 1998. The “marginal average “ discussions currently taking place in LCA fora are not included in this study.[2]

3.3 Functional unit

The functional unit describes the main function(s) fulfilled by a product system and indicates how much of this function is considered.

This study is carried out in the form of an LCA of a baseline product system which is combined with a sensitivity analysis in order to gain insight into such topics as the effects of differences in production methods, data quality, use, and countries to which the product is sold. In this sensitivity analysis data, methods and choices are varied and, in some scenarios even, the product system has been changed substantially. In order to avoid the necessity of defining a different functional unit for every scenario, it was decided to keep the functional unit applicable to all scenarios by making the definition rather broad.

[2] All inventory data is average data. In the impact assessment, both average and marginal methods are often used as the best available methods per impact category, leaving no choice here. This method is either average or marginal.

This is most useful in the present study in which a number of scenarios play an important role. For example, it makes it possible to use the same functional unit for a linoleum floor used in the Netherlands and in Sweden. However should the result of this study be used in other applications, (e.g. in a comparative assertion concerning different floor coverings) the functional unit should be defined more rigidly, in order to avoid large differences in functionality between the alternative systems.

For the definition of the functional unit, the following elements were considered:
- The function.
- The spatial context.
- The temporal context.
- The users behaviour.
- The unit.
- The quantity.

These elements are hereafter discussed in relation to the LCA on linoleum.

Function
Linoleum's function is floor covering. Linoleum floor covering can be used in different situations, e.g. in private homes, public buildings or offices. The situation and the intensity of use influence the life span of the floor. In this study we focused on linoleum floor covering in public and commercial use areas as the baseline LCA. Linoleum is sold as a floor covering mainly to hospitals, schools, offices, etc.

Spatial context
While all linoleum is produced in a factory in Assendelft[3], in the Netherlands, linoleum is used all over the world. This means that there are differences in the distance and method of transport of the linoleum floor covering as well as possible differences in the use and disposal phases. The differences between countries in the use of floor covering may include differences in maintenance (frequency of cleaning, use of cleaning products) and differences in life span (as a function of the maintenance, frequency of moving, fashion, etc.). The differences in the disposal of floor covering may include differences in recycling and differences in the ratio between combustion and dump. There may also be variance in how electricity is produced in different countries.

Because the linoleum floor covering produced by Forbo-Krommenie B.V. is used in many countries, a choice had to be made for the baseline system and the scenarios. The baseline LCA is determined as a function of the country in which most linoleum is sold, namely the Netherlands. Sweden is also a very important market for linoleum. One of the scenarios in the sensitivity analysis will, therefore, be based on Sweden. Linoleum is also sold to the USA because this has large consequences for transport distance, transport to the USA will also be included in the sensitivity analysis. To ensure the functional unit's applicability in all scenarios, no definition of the country of use is included in the functional unit.

Temporal context
1998 isthe most recent year for which Forbo-Krommenie B.V. process data is available. This year will, therefore, be the reference year for the study.

The life span of the linoleum floor can be interpreted as the technical life span or the economic life span. The technical life span is based on wear as a result of use. However, the economic life span of a floor is shorter because a floor may be removed for aesthetic reasons, for instance, when new users move into a building or when a building is renovated. This is generally referred to as the “economic life span “. The economic life span may also be influenced by the country in which the floor is used (see also spatial context). For this study, the economic life span of linoleum floors in public buildings is estimated to be 20 years (source: Forbo-Krommenie B.V.). The life span in private homes is probably shorter because people frequently replace old floor covering when moving into a new home.

User behaviour
As mentioned above consumer behaviour may differ between countries. This may influence life span and the use of maintenance products. Actual use and maintenance in a public building in the Netherlands is

[3] There also is a Forbo-Krommenie B.V. factory in Scotland. This is not included in this study.

included in the baseline system. In the Swedish scenario, we included the actual use and maintenance in a public building in Sweden, however, there was less information on Swedish maintenance than on Dutch maintenance (see Table 2 for the maintenance frequencies in public buildings in both countries).

Unit

The unit not only depends on the function, but also on the spatial and temporal context. The unit should preferably be expressed in SI units. For this study we have defined the unit as: m^2·year.

Quantity

The quantity in the baseline LCA is taken as: 40000 m^2·year. This is the use of 2000 m^2 linoleum over a period of 20 years. 2000 m^2 is representative of the floor area in an average-sized office or public building and 20 year is the economic life span of the floor in the Netherlands according to Forbo-Krommenie B.V.

This leads to the following functional unit:

The use of 2000 m^2 linoleum (produced by Forbo-Krommenie B.V. in 1998) in an office or public building over a period of 20 years.

3.4 Functionally equivalent alternative systems

After establishing the functional unit, one or more product systems capable of producing the functional unit defined above are selected.
Linoleum floor covering from Forbo-Krommenie B.V. is available in three types:

- Plain and decorative linoleum
- Corklinoleum
- Plain and decorative linoleum on a corkment backing

These are available in different gauges. For the baseline system we focused on the types of linoleum floor covering most sold, namely plain and decorative. Forbo-Krommenie B.V. sells this type of linoleum under the brand names Marmoleum®, Artoleum® and Walton. Although patterns and colours vary, the overall composition of these products is the same, with the exception of the pigments. 2.5 mm is the best-selling gauge (70% of the total return). Marmoleum 2.5 mm is, therefore, used in the baseline system. In Sweden, there is a large market for 2.0 mm Marmoleum® hence this type will be used in the "Swedish scenario ". Corklinoleum differs substantially from Marmoleum® as it is thicker (4.5 mm) and cork is used as filler instead of wood flour.

In conclusion, three different functional equivalent alternative systems are considered:

- The baseline system: This consists of the production, laying, use and maintenance of 2000 m^2 2.5 mm Marmoleum®, in an office or public building in the Netherlands, over a period of 20 years and its subsequent disposal.
- The Swedish system: This consists of the production, laying, use and maintenance of 2000 m^2 2.0 mm Marmoleum®, in an office or public building in Sweden, over a period of 20 years and its subsequent disposal.
- The Corklinoleum system: This consists of the production, laying, use and maintenance of 2000 m^2 4.5 mm Corklinoleum, in an office or public building in the Netherlands, over a period of 20 years and its subsequent disposal.

Forbo-Krommenie B.V. manufactures other products (e.g. Artoleum®, Walton) and gauges which sometimes means using slightly different production processes. However, the focus of this study was not to discuss all products manufactured by Forbo-Krommenie B.V., but rather to discuss a few relevant alternatives. Forbo-Krommenie B.V. has indicated that the three different systems described above are the most relevant.

3.5 Initial choices on methods and data

ISO requires that a number of choices on methods data and on the applicability of the study be described and discussed within the scope of the study (See ISO 14040, 140401). In accordance with Guinée *et al.* (2000) we decided to write up most of these discussions in the final report, closer to the point were these choices were made. In order to adhere closely to ISO standards, we summarised these topics below and included a reference as to where the full description/discussion on this topic may be found in the report.

- System boundaries
  In defining the system boundaries we followed the guidelines given in Guinée *et al.* (2000) which are described in the Inventory in § 4.2. The most significant choice made was to leave out the capital goods for producing linoleum.
- Criteria for inclusion of data
  Where possible in this study, we used case-specific data on processes provided by the companies were these processes take place. If this information was not complete or did not seem reliable, we used available data from other inventory studies. If case-specific information was not available, we also used other sources such as the ETH database (ETH, 1996) or data from other inventory studies. More detailed choices on the inclusion of data are described in § 4.3 and appendix A.
- Data quality
  The quality of data is discussed in the inventory section where a description of the data used in the study is given: § 4.3.
- Allocation procedures
  These are described in the section of the inventory where the allocation is carried out: § 4.4.
- Main assumptions
  The main assumptions influencing the outcome of the study are made in the inventory phase (see also above). They are, therefore, described in chapter 4 (Inventory). These assumptions concern waste treatment (incineration or landfill, substitution of useful heat when incinerating linoleum), life span, maintenance systems etc.. Other assumptions are outlined in appendix A.
- Applicability of the study
  The results of this study can be used for the application mentioned in § 2.2. The study is designed to describe the functional, alternative systems mentioned above and to analyse the not too large variations on these systems. In this form, the results cannot be used for comparative assertion or for radical changes to the system (e.g. changes leading to variance in capital goods). A more thorough discussion on data quality and the resulting applicability of the results of this study may be found in § 6.6.

3.6 ISO guidelines concerning third party reporting and peer review

Because the results of this study will probably be made public. Therefore, it has been compiled is in accordance with the ISO guidelines with respect to third party reporting. Although at present there is no comparative assertion at stake, the results may be used for this at a later stage. The study, therefore, also accords with the ISO guidelines with respect to comparative assertion and includes a peer review by an independent LCA-expert (see ISO 14040, ISO 14041, ISO 14042 and ISO 14043). This review is included in this report.

4 Inventory

In the inventory analysis, data was collected and in- and outputs were attributed to the processes. Aggregating the data ultimately resulted in a list of all environmental in- and outputs in the product system namely, the inventory table. In this chapter, all basic choices made during the construction and quantification of the product system are described. The process tree and system boundaries are described in § 4.1 and 4.2., data gathering in § 4.3 allocation of data in § 4.4 and the resulting inventory table in § 4.5 and appendix B.

For this study, we used a new software tool currently being developed at the CML: CMLCA 2.0 (Heijungs, 2000). This software is better adapted to producing results using different inventory allocation and impact assessment methods than current commercial packages. This affords the user greater freedom in defining scenarios. Unfortunately, however, the CML package is not commercially available, hence no user-friendly guide has been developed and no helpdesk exists. While this is the case, the software is available free of charge on the CML-internet site:
http://www.leidenuniv.nl/interfac/cml/ssp/cmlca.html

4.1 Process tree (baseline)

In Figure 2 the process tree for the baseline scenario is depicted.

Validity
This product system is representative for a large share of the linoleum production at Forbo-Krommenie B.V. There is, however, considerable variability in product systems for different linoleum products made by Forbo-Krommenie B.V. Therefore, in § 6.4 some alternative systems are analysed and discussed (see also § 3.4).

Reliability

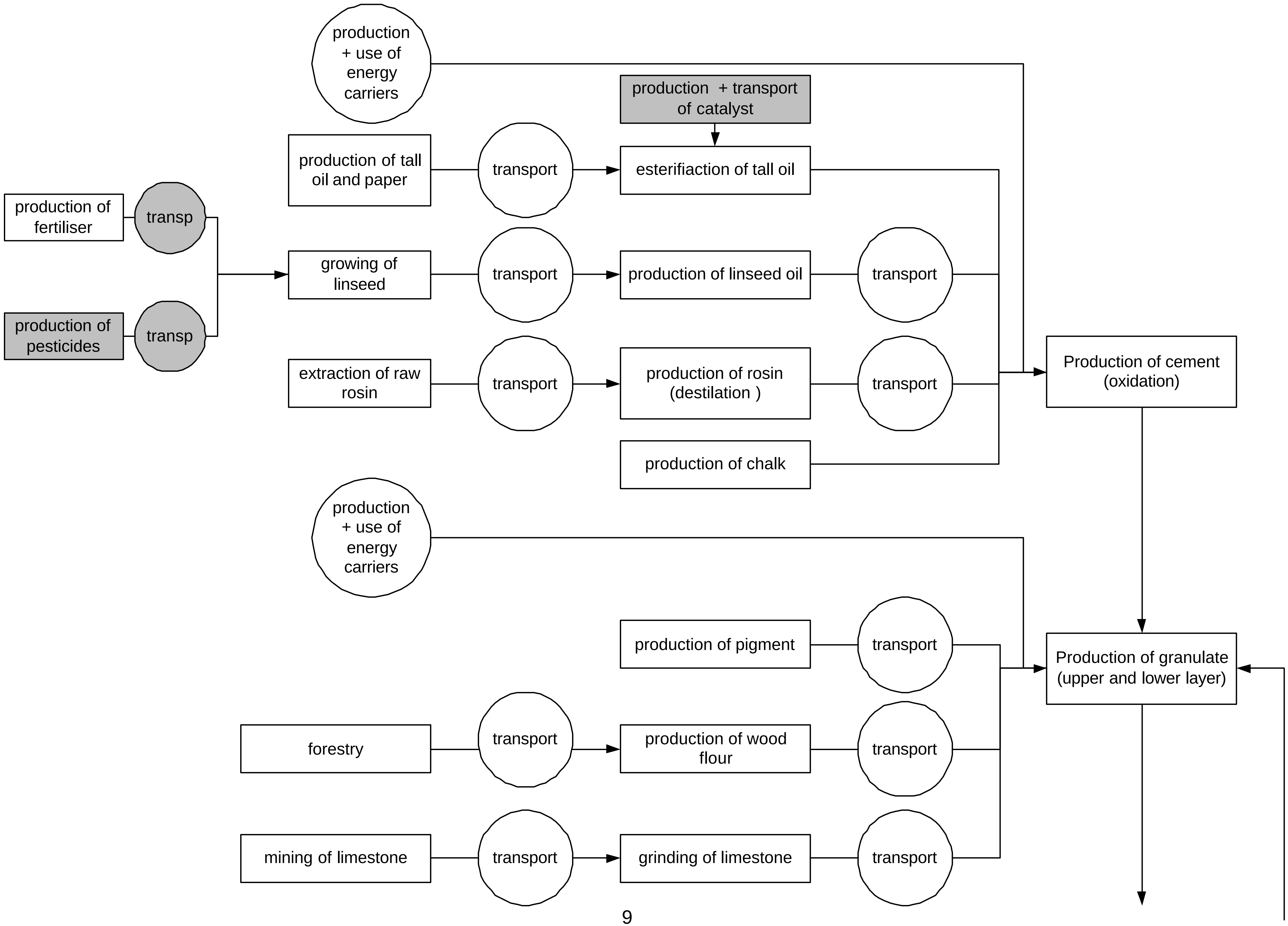
The system is not complete because capital goods are not included. All other relevant processes were included in the system. Processes for which no data was available and for which it was not possible to make a sound estime of the process data, were included in the system as “data gaps “. In

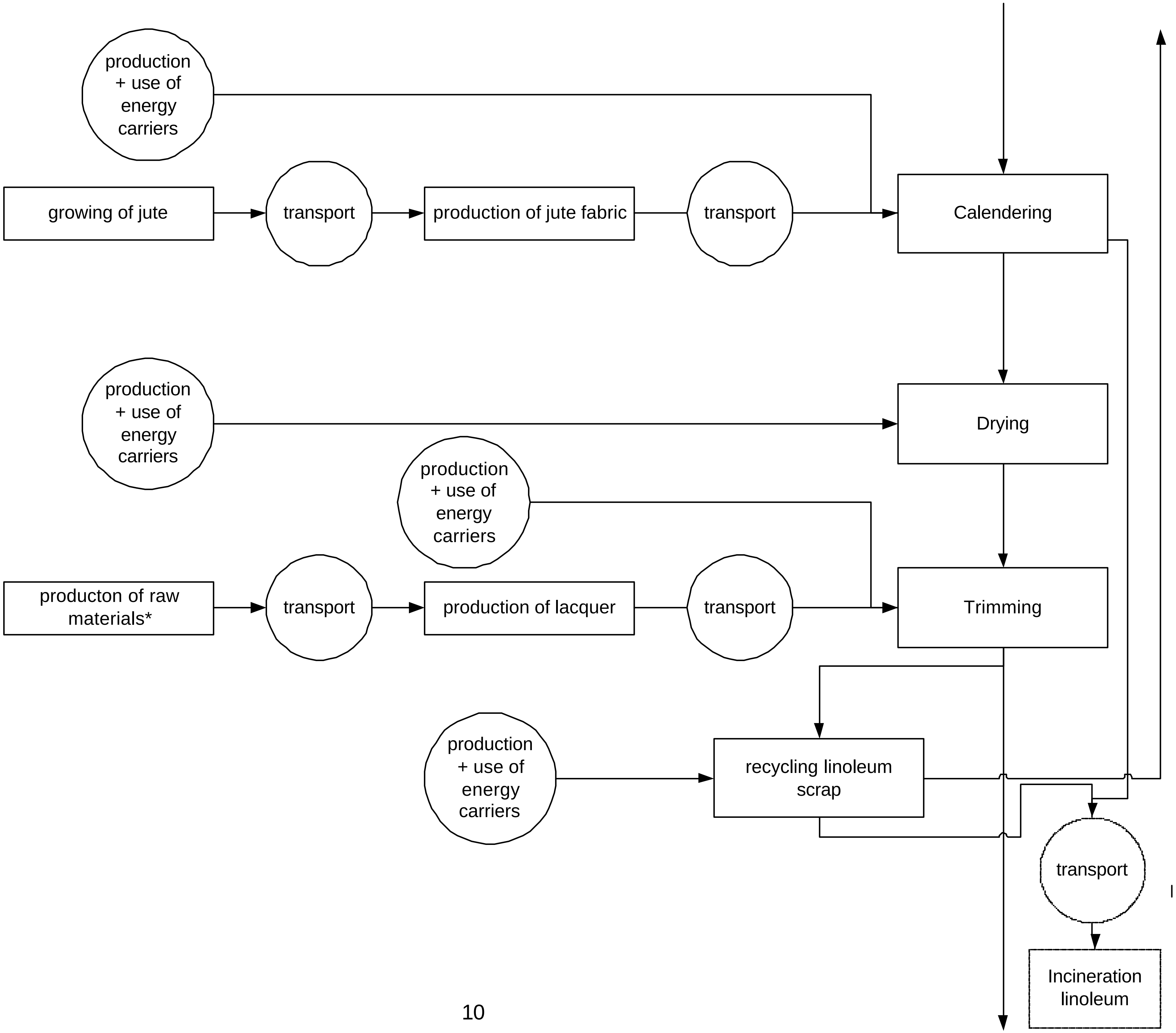
Figure 2 these are shown by a grey fill. From some processes, only part of the data could be gathered. These processes are marked with one or more asterisks. A description appears below the figure describing what is and what is not included for those processes. More detailed information may be found in appendix A.

4.2 System boundaries

In an ideal LCA situation one would be able to trace all streams up to the level of natural resources (with no human effort yet invested in the material)emissions without any further future human interventions. This, however, commonly gives rise to a problematic, infinite historical regression. Given this then, boundaries for the system must be established.

Three types of boundaries are distinguished between:
1. the product system and the environment,
2. included and disregarded processes,
3. the product system under investigation and other product systems.


production + use of energy carriers
production + transport of catalyst
production of tall oil and paper
transport
esterifiaction of tall oil
production of fertiliser
transp
growing of linseed
transport
production of linseed oil
transport
production of pesticides
transp
extraction of raw rosin
transport
production of rosin (destilation)
transport
Production of cement (oxidation)
production of chalk
production + use of energy carriers
production of pigment
transport
Production of granulate (upper and lower layer)
forestry
transport
production of wood flour
transport
mining of limestone
transport
grinding of limestone
transport


production
+ use of
energy
carriers
growing of jute
transport
production of jute fabric
transport
Calendering
production
+ use of
energy
carriers
Drying
production
+ use of
energy
carriers
producton of raw
materials*
transport
production of lacquer
transport
Trimming
production
+ use of
energy
carriers
recycling linoleum
scrap
transport
Incineration
linoleum

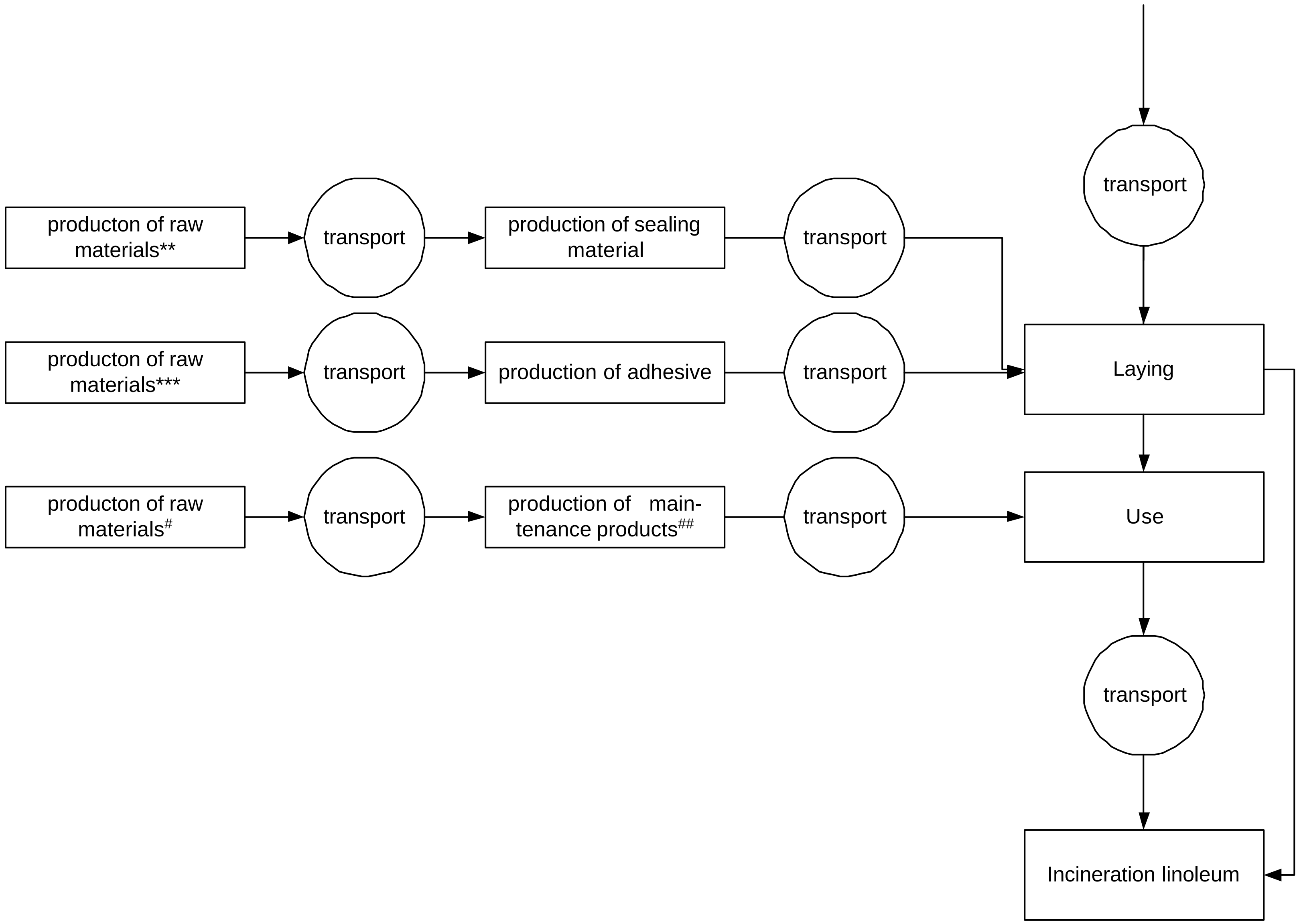


Figure 2: Process tree for the use and disposal of linoleum floors.

The production of capital goods is excluded from the system.

ad
Figure 2:
Grey fill: no data available for this process, no data on this process included in the study (sensitivity analysis on data gaps in § 6.4) .
Dash lines (incinerating linoleum): process copied from other page, duplicate.
**: information on the production and transportation distance of 96% of the raw materials was available, information on the production of ingredients for these raw materials was also partly available (= energy use, transport and waste during production of these ingredients was available, no information available on the production of ingredients for the ingredients see appendix A)*
***: Information on the production and transportation distance of none of the raw materials was available, information on the production and transportation distance of 50% of the ingredients for the raw materials was available (rosin), information on the production of other ingredients and information on energy use etc for the production of the raw materials was not available (see appendix A).*
****: information on the production and transportation distance of 98% of the raw materials was available, information on the production of ingredients for these raw materials also in part available (information on gum and limestone, as well as on energy use, transport and waste during production of some other ingredients and ingredients for these ingredients unknown see appendix A).*
#: information on production and transport of maintenance products for the Dutch scenario is available for all products with the exception of a product used to remove the polymer top layer of linoleum flooring. No information is available on the transport of maintenance products for the Swedish scenario
##:Information on the raw material production of Dutch maintenance products is not complete, information on the raw material production of Swedish maintenance products is fragmented.

The production of chalk is one step further than the grinding of limestone. Unfortunately, the data we have on the production of chalk is aggregated data which includes the precursors. Hence, we could not distinguish between the last step and the previous steps of mining and grinding. The production of chalk in this figure is, therefore, the complete aggregated production chain, which may differ from the data we used for limestone.

ad 1: Boundaries between product system and environment
There are two types of processes in this study where this type of boundary plays an important role, namely:

- The landfill processes
  In the new guide (Guinée *et al.*, 2000) it is advised to consider the landfill itself as part of the economy. Landfilling in this study is thus treated as an economic process with inputs and emissions. In this study ETH-data is used for landfills. These data is aggregated data and includes the transport, the construction of landfills and emissions.
- Agricultural processes
  In these processes, the boundary between economy and environment is often not clear. In the new guide (Guinée *et al.*, 2000) it is advised to consider the agricultural soil and the portion of the crop that is not harvested, as environment. In this study, therefore, applied pesticides are treated as direct emissions to soil, water and air. This is the case in the process "growing of linseed ". Added N and P fertilisers are understood as being emissions to the environment in as far as the amount of N and P added is not harvested. This results in an emission of N to soil and into the air (as N_2O and NH_3) in the process "growing of linseed ", since not all N added is harvested in the linseed. The P added in the process "growing of linseed " is compensated by the harvesting of P in the linseed. It is assumed that all parts of the linseed plant except the seed remain on the land and are buried or burned there. Emissions of CO_2 resulting from this are compensated by the uptake of CO_2 in the growing of linseed. The part of the crop that remains on the land is considered part of the environment and is, therefore, not accounted for[4].
  CO_2 emissions which arise from burning organic material, are compensated by the uptake of CO_2 while the raw material was growing. Both flows are not, therefore, included in the study.

ad 2: Boundaries between included and disregarded processes
The production of capital goods is not included in this study. It is very difficult to get a good estimate of the production of capital goods that may be associated with one unit of product (linoleum). As a change in the capital goods is not a logical option for improvement of environmental performance at Forbo-Krommenie B.V., it is not relevant to include this information in the study.

ad 3: Boundaries between the product system under investigation and other product systems
In some processes, the product system under consideration "connects " to another system not included in the study. These processes produce more than one product, or process more than one type of waste. In this case, allocation of the inputs and outputs of this process should take place. Allocation occurs in the following processes:

- The sawing of raw wood for other use.
- The production and transport of linseed oil to Forbo-Krommenie B.V.
- The transport, spinning and weaving of jute.
- The transport of raw rosin from the plantation and the extraction and transport to Forbo-Krommenie B.V
- The Incineration of linoleum.
- The production of tall oil and paper

Some processes from the ETH-database are used in this study (see § 4.3). These processes are already allocated when necessary. In § 4.4 the allocation of the processes is described in more detail.

Sometimes also geographical boundaries and boundaries in time are discerned. There are no geographical boundaries for this study, as the raw materials for linoleum are produced all over the world and linoleum is sold all over the world. As to boundaries in time: In this study we used the most recent data available for all processes, most data are from 1998.

[4] However, it is possible that the remainders of the linseed plant also be used commercially. suppliers of linseed oil indicate that commercially (both options occur). When linseed straw is used instead of buried/burned, the in-and outputs of the process "growing of linseed " should be allocated to the two products: straw and linseed. This would mean a lower contribution of this process to the linoleum production.

4.3 Data collection and data quality

All the economical and environmental in- and outputs are described and quantified per process. The validity (representativeness) and reliability (completeness, variability and uncertainty) of the process data are described in so far as this is possible. In the interpretation phase of the LCA, possible effects of the quality of data are analysed (see Wrisberg *et al.,* 1999).

Data was collected by Forbo-Krommenie B.V. and CML. A description is given below of the data collected, as well as of its validity and reliability.

4.3.1 Raw material production

<u>General data for the production of raw materials</u>
Data concerning production and transport (means and distance) of most raw materials used in the Forbo-Krommenie B.V. processes was provided by Forbo-Krommenie B.V.

Vvalidity
This data was provided by Forbo-Krommenie B.V. 's suppliers and should be, therefore, representative per definition for the processes concerned. Wood flour is supplied mainly by English and German suppliers, cork by Portuguese suppliers, (all cork is produced in Portugal), jute is supplied by Indian, Dutch and French suppliers(all jute is grown in India and Bangladesh), linseed oil is supplied by Dutch and German suppliers (all linseed is grown in Canada), gum rosin is supplied by Dutch and German suppliers(all raw rosin is produced in Indonesia).

Reliability
The data provided is not always complete. Figures on emissions resulting from the use of fossil fuels were often not provided. Therefore, we used aggregated ETH-data on the use of these fuels instead of data on the supply of these fuels. Data on some processes consists of rough estimates. Important assumptions are made for linseed: every year an insecticide and a pesticide are used on 20% of the linseed fields in the prescribed amount(based on personal communications from suppliers of linseed) 1% of the N applied evaporates as NH_3 and 1% as N_2O (based on Välimaa & Stadig, 1998). Data on some processes is lacking. The lacking data is mentioned in § 4.2 ad 2, and marked in the process tree. The variability may be considerable. Transportation distance in particular can vary widely because the transport is delivered by different suppliers. Data on the amount of product produced per unit of raw material varies less. We took average values for all data on raw materials where information from more than one supplier was available. Where possible, we used weighted averages based on the percentage of the raw material that Forbo-Krommenie B.V. bought from different suppliers. The uncertainty of this data is not known.

<u>Pigments</u>
The aggregated data on the production of TiO_2 used in the baseline study, and the yellow and red pigments used in the sensitivity analysis, are provided by PE Product Engineering, Germany (PE, 1999, pers. comm. K. Saur).

Validity and reliability
The validity and reliability of this data is unknown although it was more complete than the data provided by Forbo-Krommenie B.V 's suppliers . As this is aggregated data, all upstream processes such as energy use , production and the mining of Ti-ore etc. are included. Data on the transportation of the pigment to Forbo-Krommenie B.V. was based on the information provided by Forbo-Krommenie B.V.'s suppliers.

<u>Fertilisers</u>
The aggregated data on the production and transportation of fertilisers is taken from Chalmers (Davis & Haglund, 1999). An estimate of the percentage of N applied as fertiliser emitted into the air is from Välimaa & Stadig (1998).

Validity
This data is representative for the European situation, while linseed production takes place outside Europe, in Canada. While the fertilisers used in Canada are probably comparable to those used in Europe, transportation distances might differ.

Reliability
Concerning the completeness: it is not certain that the emissions resulting form the production of energy carriers are included in the data. We assumed that this was not the case and, therefore, added the ETH-data on supplied energy carriers (oil, energy etc.). We have no information as to the variability and uncertainty of the data.

<u>Other products used during raw material production</u>
The aggregated data on a few specific products (chalk, paper) was derived from the ETH database (ETH, 1996).

Validity
This data is mainly representative for European situations.

Reliability
There is no exact information on the reliability of this data, however, the list of emissions and inputs per process is very complete. ETH is high-status data and is often used in LCA-studies. However, one should keep in mind that this database is primary intended as an inventory of energy production systems. The processes closely related to the production of energy are more reliable than the more remote processes, such as production of materials.

4.3.2 Processes which take place at Forbo-Krommenie B.V.

<u>General</u>
Data on processes occurring at the production site in Assendelft is provided by Forbo-Krommenie B.V. The receipt of linoleum from the three alternative product systems is indicated in Table 1.

Table 1. The receipt of linoleum 2,5 mm (Dutch system) 2.0 mm (Swedish system) and cork-linoleum in g/m^2.

	2.5 mm	2.0 mm	cork
tall oil	398	316	380
gum rosin	76	55	3
linseed oil	588	452	842
wood flour	901	688	-
cork granulate	-	-	1329
limestone	592	441	143
pigment	101	76	263
jute	233	260	230
lacquer	12	12	10
TOTAL	2900	2300	3200

Validity
This data is per definition representative for the processes concerned.

Reliability
It is expected that the data is as complete as possible, because the authors of this study and Forbo-Krommenie B.V. had frequent contact. However, emissions resulting from the use of gasare probably not complete as only a limited list of substances was given. Therefore, we used aggregated ETH-data on the use of gas (including the production of this gas). The variability and uncertainty of the data given by Forbo-Krommenie B.V. is unknown.

VOC emissions from Forbo-Krommenie B.V.
Data on the total emissions of VOCs (not methane volatile organic compounds) from the production site are provided by Forbo-Krommenie B.V. Unfortunately, the individual VOC emissions at Forbo-Krommenie B.V. are not measured. Only the total VOC-emission is measured. Therefore, the emission of individual substances had to be estimated, based on data from Hauschild & Wenzel (1998) on VOC mixtures for solvent use. For other unspecified VOC (e.g. from ETH-processes) emissions, the VOC mixtures for stationary combustion from Hauschild and Wenzel (1998) are used.

Valididty
The data from Haschild & Wenzel (1998) is probably not very representative for the specific emissions from Forbo-Krommenie B.V.'s site.

Reliability
The completeness, variability and uncertainty of the data from Hauschild & Wenzel (1998) are unknown. However, the data seems very complete, and includes a list of great variety of individual VOCs .

4.3.3 Laying and use

Data on use and laying as well as on the products used during laying and use of the linoleum, is provided by Forbo-Krommenie B.V.

The maintenance sequences for the Dutch and Swedish systems are given in table 2.

Table 2. Maintenance sequences for the Dutch and Swedish system per 20 m^2 year (for linoleum with a life span of 20 years).

unit of operation	material used per m^2	Dutch system	Swedish system
		frequency in 20 years use	
first cleaning	0.16 l water 1.3e-3 l cleaner 0.02 l sealer	1	
dust wiping	0.005 wiping cloths	5200	240
spot cleaning	1.7e-4 l cleaner 0.02 l water	5200	
spot spraying	0.001 l spray	260	
stripping + resealing	0.02 l stripper 0.04 l sealer	6	
initial waxing	3e-3 l cleaner with wax		1
humid moping, wax	3e-5 l cleaner with wax		3120
humid mopping, detergent	3e-4 l cleaner		1040

Validity
Data on the laying and maintenance of linoleum is mainly provided by Forbo-Krommenie B.V. They are representative for laying and maintenance in public and commercial buildings.
Data on adhesives and maintenance products is provided by Forbo-Krommenie B.V.'s suppliers and should be, therefore, per definition representative for the processes concerned.

Reliability
Data on the production of laying and maintenance products is including emissions, material use and energy use. Information on the production and transportation distance of 100% of the raw materials used for sealing material is available, information on the production of ingredients for these raw materials is also available in part. Information on the production and transportation distance of 98% of the raw materials used for adhesives is available, information on the production of ingredients for these raw

materials is also available in part. Information on production and transport of maintenance products for the Dutch scenario is available for almost all products (except for a product used to remove the old seals of a linoleum floor). Information on the production and transport of maintenance products for the Swedish scenario is not complete. Information on the raw material production of Dutch maintenance products is not complete. Information on the raw material production of Swedish maintenance products is fragmented (see appendix A). No information is available on the variability and uncertainty of the data.

4.3.4 Incineration of linoleum

Data on the incineration of linoleum is from TNO and provided by Forbo-Krommenie B.V. (van Loo & de Koning, 1994). All linoleum waste from the calenders, the trimming department and final disposals is assumed to be incinerated. It is assumed that the waste that remains during laying goes to landfill. The CO_2 emissions during the incineration of linoleum are not included in the study. They are compensated by the uptake of CO_2 by the linseed and wood, which serve as the raw material for linoleum.

Validity and reliability
The data concerning which part of the linoleum is burned and which part is land filled is based on assumptions. Other assumptions are also possible. The data on the emissions and energy content wile incinerating linoleum is, per definition, representative for the processes concerned because the analysis and calculations carried out by TNO (well known Dutch independent research institute) are carried out on linoleum manufactured by Forbo-Krommenie B.V. The assumption made by Van Loo & De Coning that the efficiency of energy production while incinerating linoleum can be 75%, seems too high. In this study, we used a lower but still high value of 40%. However, this high value is not unrealistic when we look only at the marginal change in electricity production when adding a certain amount of linoleum to an already working waste incineration.

4.3.5 Other processes (transport, energy, landfill)

Data on transport, by truck, boat and train, production and use of energy carriers, and landfilling is derived from the ETH database (ETH, 1996).

Validity
Electricity:

Electricity data is very detailed in the ETH database. Given this, the electricity needed for those processes which take place on Forbo-Krommenie B.V.'s site, Dutch electricity production could be taken to be representative. For other electricity use, the European average was taken. This data is representative for the European situation but perhaps not for other countries.

Other energy carriers, transport and landfill:

Data on the use of other energy carriers, and transport is representative for European situations. Their representativeness for non-European countries (India, Indonesia, and Canada) is not known. This data is mostly representative for European situations. Emissions from transport by truck in Asian countries such as India and Indonesia are possibly higher because the trucks that are used are older and the fuel used might be different.

Landfill:

For all types of waste in this study, data for landfill sites from the ETH-database are used. These are aggregated data from landfill sites for inert waste, hazardous waste, chemical waste and radioactive waste. The data include the infrastructure and the long term emissions from the different types of landfill sites. These emissions are probably not very representative for emissions resulting from linoleum, or other specific wastes. However, this was the only date available.

Reliability
Landfill:

All the data we used came from the ETH-database and is aggregated data, meaning that all processes are followed from the cradle. This means that, in the case of landfill, also the infrastructure (building of the landfill site etc.) necessary for landfilling is included. Also, long-term emissions from landfill are included.

Energy and transportation:

This cradle approach was also applied in the case of transportation processes and energy carriers. There is no exact information on the reliability of data although the list of emissions and inputs per process is very complete. ETH is high-status data and often used in LCA-studies. However, one should keep in mind that this database was created primarily as an inventory of energy production systems. The processes closely related to the production of energy are more reliable than more remote processes, such as landfilling and transport.

4.3.6 Conclusions on data quality

Most data on the production of raw materials is representative for the specific processes, but reliability is not known. They differ largely in completeness. Data on the processes which take place at Forbo-Krommenie B.V. is representative and probably more reliable (because more complete) than that on the production of raw materials. Data on the composition of the VOC emissions is lacking. The data on the incineration of linoleum is representative and seems complete. However, the assumption that electricity is produced with 40% efficiency might be somewhat high. The ETH data is probably representative and reliable for the energy data. The data on transportation processes, landfill processes and other processes is probably less representative and reliable.

In § 6.4 sensitivity analysis in the form of scenarios is carried out to study the effects of changes in data for processes with a high influence on the results for which the data is less reliable.

4.3.7 Data gaps

No process data was available for the following processes:

- The production and transport of pesticides (the use and emission of pesticides is included).
- The production and transport of some raw materials needed for maintenance products (additives, thickeners, solvents) and virtually all of the ingredients for those materials.
- The production and transport of some raw materials needed for the production of materials used during laying (adhesives and material used to seal the seams of professionally used linoleum floors).
- The production and transport of a catalyst needed in the process “esterification of tall oil “.
- The production and transport of the fertiliser S needed in the process “growing of linseed “.
- The production and transport of the maintenance product used for removing the top layer of linoleum floor covering needed in the process “the use and maintenance of 1m2 linoleum for 20 years “.

In § 0 a sensitivity analysis is carried out to study the effects of these datagaps.

4.4 Multiple processes (allocation)

There are three kinds of multiple processes, namely:

- Co-production: simultaneous production of economically valuable products, goods or services.
- Combined waste disposal: simultaneous processing of more than one stream of waste, with a negative value .
- Open-loop recycling: processing a waste stream of one production process so that it can be reused in another.

Furthermore, a combination of these multiple processes may be found, such as the production of electricity (valuable product) through a waste incinerator.

For these multiple processes, a solution has to be found by either avoiding multiple processes by dividing the process into sub-processes or by enlarging the system under investigation so that the co-products are also involved, or by allocation (dividing the in- and outputs of the processes over the products). According to ISO 14041 (1998), the following steps have to be taken when multiple processes occur:

Step 1
If it is possible, one should try to avoid allocation by dividing the multiple processes into sub-processes or by enlarging the system under investigation so that the co-products are also included.

Step 2
If it is not possible to do so, an allocation based upon causal physical relations is preferred; e.g. the amount of mercury (Hg) in the emission of a waste combustion laying may be attributed to every product containing mercury to be burned according to its content.

Step 3
If it is not possible to make an assessment based on a causal physical relationship, then other relations should be used such as an allocation proportional to the economical value of the products.

In § 4.2 ad 3 the multiple processes for the product system under investigation have been mentioned. In this study, we followed the three ISO 14041 steps as closely as possible. In only one case an ISO step-one procedure (substitution) could be applied (see ISO 14041, 1998). Expansion of function was not applied because it could result in a very large and complex system, producing many products. It would then be difficult to identify possible improvement options for Forbo-Krommenie B.V. ISO step-two procedures (allocation based on causal relations) were not possible (see ISO 14041, 1998). Most processes that had to be allocated involved co-production. In these cases, allocation based on causal physical relations is almost never possible. In most cases, therefore, an ISO step-three procedure was followed (see ISO 14041, 1998). Where possible, we used the economic value of the products because we feel the trigger for a production process will be the product with the highest economic value. Where this was not possible, we carried out a mass-based allocation (which is less desirable because the product with the highest mass is not automatically the one which triggers the process) or a proxy.

Allocation occurred for the following processes:

- The sawing of raw wood for other uses.
  - This process produces wood remainders and production wood.
  - In this case, the inputs and outputs of the process are partitioned between the two products, based on their economic value (step 3 procedure). The remainders form 45% of the total mass produced. The value of production wood is a factor 4.5 higher than that of the wood remainders. Therefore, 15% of the total value produced is from wood remainders.
- The production and transport of linseed oil to Forbo-Krommenie B.V.
  - This process produces linseed oil and linseed expellers (used as cattle fodder) .
  - In this case, the inputs and outputs of the process are partitioned between the two products based on economic value (step 3 procedure). The value of the produced linseed expellers is not negligible. It is 43% of the total value produced.
- The transport, spinning and weaving of jute.
  - This process produces jute and re-usable jute waste.
  - In this case, all in- and outputs are allocated to the jute (step 3 procedure) because the value of the amount of jute-waste produced is almost negligible compared to the jute.
- The transport raw rosin from the plantation and the extraction and transport to Forbo-Krommenie B.V.
  - This process produces gum rosin and turpentine.
  - In this case, the inputs and outputs of the process are partitioned between the two products based on economic value (step 3 procedure). The value of the produced gum rosin is 91 % of the total value produced.
- The production of tall oil and paper[5].
  - This process produces tall oil and paper

[5] In this study we did not separate the production of pulp and paper. Often these processes take place in the same factory. Therefore, the in- and-outputs in the production of paper and tall oil are allocated over the products tall-oil and paper. If pulp-production were seen as a separate process, the allocation should take place over the products tall oil and pulp. This would mean a different allocation as the economic value of the pulp is probably much lower than that of the resulting paper leading to a higher contribution of this process to the linoleum production.

  > The inputs and outputs of the process are partitioned between the two products based on economic value (step 3 procedure). The value of the amount of tall oil produced is only 1% of the total produced value.
- The incineration of linoleum.
  > This process treats waste and produces energy.
  > The produced energy has to be allocated. This is done by seeing the energy as a substitute for another process, that being the production of electricity in the Netherlands (ETH-process for Dutch average electricity), with an efficiency of 0.4 (step 1 procedure).

Conclusion for six processes the in- and outputs had to be allocated, namely
- The sawing of raw wood for other use.
- The production and transport of linseed oil to Forbo-Krommenie B.V.
- The transport, spinning and weaving of jute.
- The transport of raw rosin from the plantation and the extraction and transport to Forbo-Krommenie B.V.
- The production of tall oil and paper .
- The incineration of linoleum.

In five cases, economic allocation was applied and in one case -the incineration of linoleum- a substitution has taken place.

4.5 The inventory table of the baseline product system

Data collection has resulted in a database with processes and accompanying in- and outputs. These processes are coupled based on the functional unit. An inventory table is then the result of aggregation and of scaling all data for the process tree.

In this LCA study, calculations were made using CML software. The CML package uses the matrix method to calculate the inventory table which belongs to the functional unit (ILV,1991; Heijungs, 1992).

The inventory table of the baseline product system and the two alternative equivalent systems is given in appendix B.

5 Impact assessment

In the impact assessment, the potential effects of the in- and outputs are identified and characterised. For the baseline and most scenarios, the impact categories as well as characterisation and normalisation are based on Guinée *et al.* (2000). This is briefly described in § 5.1 to 5.4.
There are, however, other impact assessment approaches which are also applied to the baseline system as sensitivity analysis scenarios. These methods are briefly described in § 5.5. Not all of these methods are in accordance with ISO standards. Methods and scenarios that do not follow the ISO standards are described in separate textboxes, so that any third party reading the report can recognise them as such. When comparing the different impact assessment methods, the approach of Guinée *et al.* (2000) is referred to as CML-2000. In § 5.6 the environmental profile of the baseline system is described and in § 5.7 the inputs and outputs not assigned to an impact category are listed.

5.1 Selection of impact categories

It was first established which of the environmental problems and impact categories are taken into account. In this study, the impact categories are based on Guinée *et al* (2000), as presented in Table 3. Depending on the expected emissions and extractions taking place during the life cycle of linoleum floor coverings, the relevant categories were selected from this list.

Table 3. Default list of impact categories

Impact category	Spatial scope
A. Input related categories	
Extraction of abiotic resources	global
Extraction of biotic resources	global
Land use	
subcategory: Increase of land competition	local
subcategory: Degradation of life support functions	Cont/reg/local
subcategory: Degradation of biodiversity	Cont/reg/local
B. Output related categories	
Climate change	Global
Depletion of the ozone ayer	Global
Human toxicity	Glob/cont/reg/loc
Eco-toxicity	
subcategory: aquatic eco-toxicity fresh water	Glob/cont/reg/loc
subcategory: aquatic eco-toxicity sea water	Glob/cont/reg/loc
subcategory: terrestrial eco-toxicity	Glob/cont/reg/loc
subcategory: sediment eco-toxicity fresh water	Glob/cont/reg/loc
subcategory: sediment eco-toxicity sea water	Glob/cont/reg/loc
Photo-oxidant formation	Cont/reg/loc
Acidification	Cont/reg/loc
Eutrophication	Cont/reg/loc
Odour	Local
Noise	Local
Radiation	Regional/local
Casualties	Local
Waste heat	Local

In Table 4 the impact categories considered in this study are listed. The characterisation factors for these 11 impact categories are listed in appendix C. Below, these categories and the corresponding indicators are explained briefly. For a more detailed description and justification of the chosen indicators we refer to Guinée *et al.* (2000), in which the indicators are described according to ISO standards.

Table 4. Impact categories, methods and normalisation data for the impact assessment method according to Guinée *et al.* (2000)

Impact category	characterisation method	unit	Normalisation data
A. INPUT RELATED CATEGORIES			
Extraction of abiotic resources	Guinée (1995)	kg antimony eq.	2.20E12
B. Output related categories			
Climate change	Houghton et al (1994 & 1995)	kg CO_2 eq.	2.27E13
Depletion of the ozone layer	WMO (1991, 1995, 1998)	kg CFC-11 eq.	3.61E8
Human toxicity	Huijbregts (1999a)	kg 1,4-dichloro-benzene eq.	1.45E13
Eco-toxicity			
subcategory: aquatic eco-toxicity[6]	Huijbregts (1999a)	kg 1,4-dichloro-benzene eq.	7.61E13
subcategory: terrestrial eco-toxicity	Huijbregts (1999a)	kg 1,4-dichloro-benzene eq..	1.13E11
subcategory: sediment eco-toxicity[6]	Huijbregts (1999a)	kg 1,4-dichloro-benzene eq.	9.19E12
Photo-oxidant formation	Derwent *et al*. (1998) and Jenkin & Hayman (1999)	kg ethylene eq.	6.26E9
Acidification	Huijbregts (1999b)	kg SO_2 eq.	6.41e10
Eutrophication	Heijungs *et al*. (1992)	kg PO_4 eq.	1.08e11
Odour	Heijungs *et al*. (1992)	m^3	4.96e17

Extraction of abiotic resources

Problem definition:

The decrease of abiotic resources, the "dead " material resources such as iron ore, fossil fuels etc. that occur as inflows in LCA.

Indicator:

The method based on the current reserves and the rate of deaccumulation of these reserves developed by Guinée (1995).

Climate change

Problem definition:

The effect of emissions as a result of human activities on the radiative forcing (=heat radiation absorption) of the atmosphere. This, in turn, can result in adverse effects on ecosystem health, human health and material welfare. Most of these emissions enhance the radiative forcing, resulting in a rise in the earth's temperature. This is popularly referred to as the "Greenhouse effect ".

Indicator:

The Global Warming Potentials (GWPs) of the IPCC. The GWP of a substance is the ratio between the contribution to the heat radiation absorption resulting from the instantaneous release of 1 kg of a greenhouse gas and an equal emission of carbon dioxide (CO_2) integrated over time (Houghton *et al.,* 1994 & 1995).

Depletion of the ozone layer

Problem definition:

[6] In a recent update of Huibregts (1999a) that became available during the writing of this study, these subcategories are split into two fresh water and salt water. For this study we decided to use the old list of only three subcategories because using the new list would imply changing all water-emission figures in the database, which was not possible in the time left. We did use the new characterisation factors, but we added the characterisation results for fresh water and marine systems weighted in the way the old factors were weighted, based on the respective volumes of salt water and fresh water for the aquatic factors and weight of the salt water and fresh water sediment. This basically meant that the salt water compartments prevailed, because of their high factors and large volume/weight.

The problem of the breakdown of stratospheric ozone as a result of human emissions. Because of the thinning of the ozone layer, a larger fraction of the sun's UV-B radiation reaches the earth's surface. This can have harmful effects on human health, animal heath, terrestrial and aquatic ecosystems, biochemical cycles, as well as on materials.
Indicator:
The Ozone Depletion Potentials of the WMO. The ODP is defined as the ratio between ozone breakdown in a state of equilibrium due to annual emissions (flux in $kg \cdot yr^{-1}$) of a quantity of a substance released into the atmosphere and the breakdown of ozone in a state of equilibrium due to an equal quantity of CFC-11 (WMO, 1991, 1995, 1998).

Human Toxicity:
Problem definition:
This impact category contains the effects of toxic substances in the environment on humans.
Indicator:
The characterisation factors from Huijbregts (1999a) based on modelling the fate of toxic substances, along with exposure and risk for humans with the fate model USES-LCA.

Ecotoxicity
Problem definition:
Eco-toxicological impacts are the effects of toxic substances on aquatic, terrestrial and sediment ecosystems.
Indicator:
The characterisation factors from Huijbregts (1999a) based on modelling the fate of toxic substances, along with risk for ecosystems with the fate model USES-LCA.

Photo-oxidant formation
Problem definition:
Photo-oxidant formation is the formation of reactive substances (mainly ozone), which are injurious to human health and ecosystems, and which may damage crops.
Indicator:
The Photochemical Ozone Creation Potentials (POCPs). A POCP of a VOC is the ratio between the change in ozone concentration due to a change in the emission of that VOC and the change in ozone concentration due to a change in the emission of ethylene (Derwent *et al.,* 1998 andJenkin & Hayman, 1999).

Acidification
Problem definition:
Acidifying substances cause a large number of diverse impacts on soil, groundwater, surface water, organisms, ecosystems and materials (buildings). Examples are fish dying in Scandinavian lakes, forest decline and the crumbling of building materials.
Indicator:
The average European factors from Huijbregts (1999b). This method accounts for fate and regional sensitivity from ecosystems.

Eutrophication
Problem definition:
Eutrophication includes all impacts due to a too high level of macro-nutrients in the environment. Nitrogen (N) and phosphorus (P) are the most important eutrophicating elements. This enrichment may cause an undesirable shift in the composition of a species and an increased production of biomass within aquatic and terrestrial ecosystems. In addition, high nutrient concentrations can also make surface waters unacceptable for drinking water supply. An increased production of biomass in aquatic ecosystems may lead to low oxygen concentrations because the decomposition of this biomass needs oxygen (measured as BOD). This is also placed in the same category.

Indicator:

The factors from Heijungs *et al*. (1992) based on the contribution of N and P to the average composition of aquatic organisms: $C_{106}H_{263}O_{110}N_{16}P$, which is assumed to be representative of the average composition of biomass.

<u>Odour</u>
Problem definition:
Odour is a problem when a given concentration of odorous substances is experienced as unpleasant. Whether or not an odour will be experienced as stench will depend on the individual exposed to it. However, above a certain emission level all individuals will experience this odour as stench.
Indicator:
The factors in Heijungs *et al*. (1992), based on Odour Threshold Values (OTV). The OTV of a substance is the concentration of a given substance, under defined standard conditions, at which 50% of a representative sample of the population can just detect the difference between a sample of air mixed with that substance and a sample of clean air.

<u>Other impact categories</u>
For most of the other categories mentioned in Table 3 the characterisation methods are not yet operational (extraction of biotic resources, land use, noise and radiation). The category casualties, noise, and waste heat are not taken into account in most LCA-studies, unless there is reason to believe that they are especially important for the study. This is not the case for the present study. These categories are very local and the results are difficult to interpret in relation to the other categories. Moreover, for these categories there is no normalisation data, so it is impossible to compare these categories to the others, because they are not in the same dimensions.

The reasoning above also holds for the impact category "odour ". However, "odour " is an important category for Forbo-Krommenie B.V. because of the typical linoleum "odour ". Therefore "odour " was included in the study. However the emissions of the VOCs which give rise to the "odour " at Forbo-Krommenie B.V. are not known individually. It would be necessary to have this information for each individual case in order to properly include this category in an LCA. In the present case we had to make an estimate, which makes the results for this category somewhat more uncertain than those for the other categories. In § 6.4.4 we carried out a sensitivity analysis to study the effects of this estimated VOC-composition on "odour ".

5.2 Classification and characterisation

In this step, the in- and outputs are attributed to all relevant impact categories and the contribution to the different impact categories iscalculated based on the characterisation factors/methods chosen. All in- and outputs are taken to contribute to these categories to their potential full amount, which means that we did not account for the possible occurence of parallel impacts (= the contribution of the substance to one impact category diminishes the contribution to another) to occur. The characterisation factors used in this study are listed in appendix C, based on the preferred methods listed in Guinée *et al.* (2000). The results are aggregated per impact category. This then yields in one indicator result per impact category.

5.3 Normalisation

In this step, the indicator result per impact category is given as a fraction of the reference contribution of a certain region or person, over a particular interval of time, to this impact category. Among these reference contributions (normalisation data) one may find the annual contribution to the impact categories under consideration per the entire world, or the Netherlands, or a world citizen. The normalisation step makes it possible to compare the contributions of the different impact categories, since they are now in the same dimensions: e.g. a fraction of the annual worldwide (or Dutch) contribution to this category. As a step towards grouping and weighting, normalisation often is indispensable.

In this study, the results are normalised based on the contribution of the world in 1989 to abiotic depletion and the contribution of the world in 1992/1993 to the output-related categories. The last figures are based on Dutch emissions of pesticides in 1992 and other substances in 1993, extrapolated to the world level. This is the most recent normalisation data available (source: Blonk *et al.,* 1997). Normalisation data is given in Table 4.

5.4 Grouping and weighting

Following normalisation, the results per impact category may be grouped or even weighted.

Grouping means that the categories are being formed, sorted and, if desired, classified. One might, for example think of classifications based upon the spatial scale of a certain environmental problem (local, regional, global), or of a classification based on a scale of relative importance. In this way, results are presented in an orderly fashion.

Weighting on the other hand, goes somewhat further. The results for a certain category are multiplied by a weighting factor. Such a factor is based on the relative importance of the particular impact category. This makes it possible to compare different categories and even add them up to get one one final LCA-result. The weighting factors may be based on different approaches. Guinée *et al* (2000) recommend basing these weighting factors on some form of panel method. A number of methods are available based upon the 'panel-method' through which a representative panel attributes weighting factors to the different environmental problems. However, these methods only concentrate on a part of the effect categories.

ISO 14042 (1999) does not permit weighting in cases where the results of an LCA will be used for a comparative assertion, that is, comparison of products for which the results will be used externally. Yet while this is the case for weighting, grouping is allowed in comparative assertion. Unfortunately no practical methods for grouping are yet known to the authors of this study.

Because no complete weighting set covering all relevant impact categories is available at the present time, we did not carry out a weighting for the three equivalent alternatives studied. However in order to compare the results of the method described by Guinée *et al.* (2000), which will, for convenience sake, be referred to as the CML 2000 with methods which combine impact assessment and weighting in one factor, we had to apply a weighting to the CML-2000 results (see further § 5.5). We chose to weight all impact categories equally with a factor 1 with the exception of the ecotoxicological impact categories which are weighted together as one (so that each of the three ecotoxicological categories was weighted with a factor 1/3).

5.5 Other impact assessment methods

To check to what extent the results of the study are influenced by the method of impact assessment that is used, 5 different impact assessment methods were compared to the method used in this study in the scenario analysis

- The Ecoindicator 95 (Goedkoop, 1995)[7]
- The ExternE method (EC, 1995)
- The EPS system (Steen, 1993; Steen 1996)[7]

Impact assessment method not following the ISO standards:

- The Ecoscarcity method, two versions (Ahbe et al, 1990; Braunschweig et al, 1994)

These methods are described briefly below. The method used in this study is referred to, for convenience, as the CML 2000 method. For a more extended description we refer the reader to the literature cited.

[7] Recently, a new version of the ecoindicator (the ecoindicator 99) and EPS were published. However, these methods were not yet available at the moment that the database CMLCA was being set up.

In the Ecoindicator 95 (Goedkoop, 1995), the impact categories are more or less similar to those in the CML 2000 method. The main difference is that, in the characterisation phase, no inter-effect weighting takes place for toxic substances (metals, pesticides and carcinogenic substances are treated separately). They are weighted against each other using a distance-to-target method. The targets are based upon a *defined* no-effect level, assumed at safeguard subject level.

In the ExternE method (ExternE, 1995) or the Impact Pathway Analysis, the damage of an emission is calculated using fate models and exposure–damage functions. In principle, the damages are valuated on the basis of willingness-to-pay. Although the damages could probability be calculated and presented separately from the valuation step, this is seldom done. Mostly, one set of factors is applied directly to the emission and extraction data, which is not in accordance with ISO standards.

The EPS (Steen, 1993; Steen, 1996) method is a valuation method based on safeguard subjects and a valuation based on willingness-to-pay. Although the contribution to the safeguard subjects could be calculated and presented separately from the valuation step, this is seldom done. Moreover the list of safeguard subjects is rather limited. Mostly, one set of factors is applied directly to the emission and extraction data, which is not in accordance with ISO standards. The method and the derivation of factors are not transparent.

Impact assessment methods which do not follow the ISO standards:
In the Ecoscarcity method (Ahbe et al. 1990; Braunschweig et al. 1994; Baumann, 1992) interventions are weighted against each other directly at the level of emissions and extractions, using a distance-to-target method based on (Swiss or Norwegian) policy targets. All goals are considered equally important. One important drawback to the method is its dependence on the goals in time and country.

5.6 Environmental profile of the baseline system

In Table 5 the results of the characterisation and normalisation phase are shown.

Table 5. Environmental profile of the baseline system

categories	characterisation results		normalisation	results	
Depletion of abiotic resources	1.12E+03	kg antimony eq.	5.09E-10	yr.	
Photochemical oxidant formation	1.06E+01	kg ethylene eq.	1.69E-09	yr.	
Depletion of the ozone layer	2.06E-02*	kg CFC-11 eq.	5.69E-11*	yr.	
Global warming	1.72E+04	kg CO2 eq.	7.58E-10	yr.	
Human toxicity	8.30E+03	kg 1,4-dichlorobenzene eq.	5.71E-10	yr.	
Aquatic ecotoxicity	8.40E+05	kg 1,4-dichlorobenzene eq.	1.10E-08	yr.	** 3.13E-8
Sediment ecotoxicity	7.38E+05	kg 1,4-dichlorobenzene eq.	8.07E-08	yr.	
Terrestrial ecotoxicity	2.36E+02	kg 1,4-dichlorobenzene eq.	2.09E-09	yr.	
Acidification	8.44E+01	kg SO2 eq.	1.32E-09	yr.	
Eutrophication	1.29E+01	kg PO4- eq.	1.19E-10	yr.	
Odour	1.59E+08	m3	3.20E-10	yr.	

Ex = $\cdot 10^x$

*: These numbers would be 8% higher if the leak of HCFC-22 at the calenders at Forbo-Krommenie B.V. in 1998 were included. However, this leak is regarded in this study as an incident.

**: average of the results for the three ecotoxicity subcategories

5.7 Inputs and outputs not assigned to an impact category

In total 264 inputs/outputs are not assigned to an impact category. These are listed in appendix D. These are mainly from the ETH database. A large share (132 emissions) of the emissions are radioactive emissions. Since the impact category “radiation “ is not included in this study (because no consensus has yet been reached on which impact assessment method to use for this category), these radioactive emissions could not be included in the impact assessment results. Also, some inputs are also not assigned to an impact category. The input of land is not included, because a method for the impact category “land-use “ is still in development. For other inputs no characterisation factors have as yet been developed.

6 Interpretation

In the interpretation, the results of the life cycle inventory and the life cycle impact assessment (LCIA), are summarised, analysed and discussed as a basis for conclusions, recommendations and decision making, in accordance with the goal and scope.
In ISO document 14043 (1998) it is proposed that interpretation be carried out in three steps:

- Identification of the significant issues.
- Evaluation.
- Conclusions, recommendations and reporting.

These steps were followed in the present study on linoleum floors. The first two steps are followed in a recursive process. Conclusions are based on the combined results of the two preceding steps.

The aim of the identification of significant issues is to get answers to the questions defined in the goal and scope of the study. In this study, two types of analysis were carried out:

- Contribution analysis: Significant contributions to the total result are mapped by expressing, for example, the contribution of substances, processes, life cycle stages and/or impact categories in % of the total results. The results of the contribution analysis for the baseline system are reported in § 6.1.
- Anomaly Assessment: On the basis of experience, for example, unusual or remarkable deviations from expected or normal results are determined. This is a method of checking for possible errors. These errors can then be repaired by adjusting the "incorrect " input data or model choices etc. Unusual results remaining at the end of the study (ergo, which are not the result of a repairable error) which cannot be explained are reported.

After the presentation and analysis of the results for the baseline system in § 6.1, the reliability and validity of the data is further checked in the evaluation which is described in the following sections. "The objectives of the evaluation are to establish and enhance the confidence in and the reliability of the result of the study " (ISO 14043, 1998). The ISO 14043 guidelines are not yet worked out in detail. ISO mentions a completeness check, a sensitivity check, a consistency check, an uncertainty analysis and an assessment of data quality as elements of the evaluation. Van den Berg *et al.* (1998) give a framework for quality assessment in LCA. They distinguish between validity and reliability of input (process) data and models. Validity refers to representativeness, consistency, relevancy, as well as to whether or not data and models match the scope of the study. Reliability refers to reproducibility, uncertainty, completeness, etc. The validity and reliability of the product system, data and methods is considered throughout the entire study (see, for example, the description of the product system, process data and allocation methods in § 4.1 to 4.4 and the consequences of data quality in § 6.1.4), but conclusions on the effects of data quality can only be drawn after such an evaluation.

In § 6.2 a first validity check of the total results for the baseline system is carried out by comparing the results of this study with results from other studies on linoleum floor coverings. In § 6.3 and § 6.4 the reliability of product system, data and methods is further checked through various forms of sensitivity analysis. In § 6.3 a perturbation analysis is carried out. In this analysis, the influence of small variations on the results in each individual economic and environmental flow is analysed. The result can be used to answer the question for which flows the result is the most sensitive. These are the flows for which the ratio between change in result and change in flow are highest. In § 6.4 the sensitivity of product system, data and methods is checked by means of different scenarios. Data quality is one of the reasons for carrying out some scenarios. Finally in § 0. the consequences of the datagaps (completeness check) are evaluated.

Conclusions and recommendations are treated in chapter 7.

6.1 Contribution analysis

In the contribution analysis, the contribution of the different stages in the production chain, processes, emissions and extractions is analysed. This analysis provides insight into the most important stages, processes and flows contributing to a certain impact category. This insight may be used in several ways. First, the knowledge may be combined with the knowledge on data quality. Clearly, the most important stages, processes and flows should be based on valid and reliable data. Important processes or flows that are based on low quality data might be analysed further in a sensitivity analysis. Second, the processes that contribute much to the impact categories are the first processes to focus on, when looking for opportunities for improvement.

6.1.1 Impact categories

In the last column of Table 5, the characterisation and normalisation results are presented for all categories. The one result for ecotoxicity is the average for all 3 ecotoxicity categories. The result for ecotoxicity is very high, approximately a factor 20 higher than the result for the next "important " categories namely, acidification and oxidant formation. In most weighting methods, the weighting factors differ no more than a factor 10. Therefore, aquatic ecotoxicity is probably the most important impact category when a combined result would be calculated based on some sort of weighting. This is not done here as no encompassing weighting method is available and ISO does not permit weighting for comparative assertion.

The result for "odour " should be considered with some care, as the emissions of VOC from Forbo-Krommenie B.V. were not specified. The total amount of VOC was known, but not the individual substances. To calculate the contribution of the VOC-emission to the different categories, the individual substances in this VOC-emission had to be known. These are estimated based on solvent use (source: Hauschild & Wenzel,1998). However, it is not known if this mixture of individual VOC is representative for Forbo-Krommenie B.V.

6.1.2 Stages

In Figure 3, the contribution of the different life cycle stages to the category results is presented. The total of all positive contributions is set at 100%.

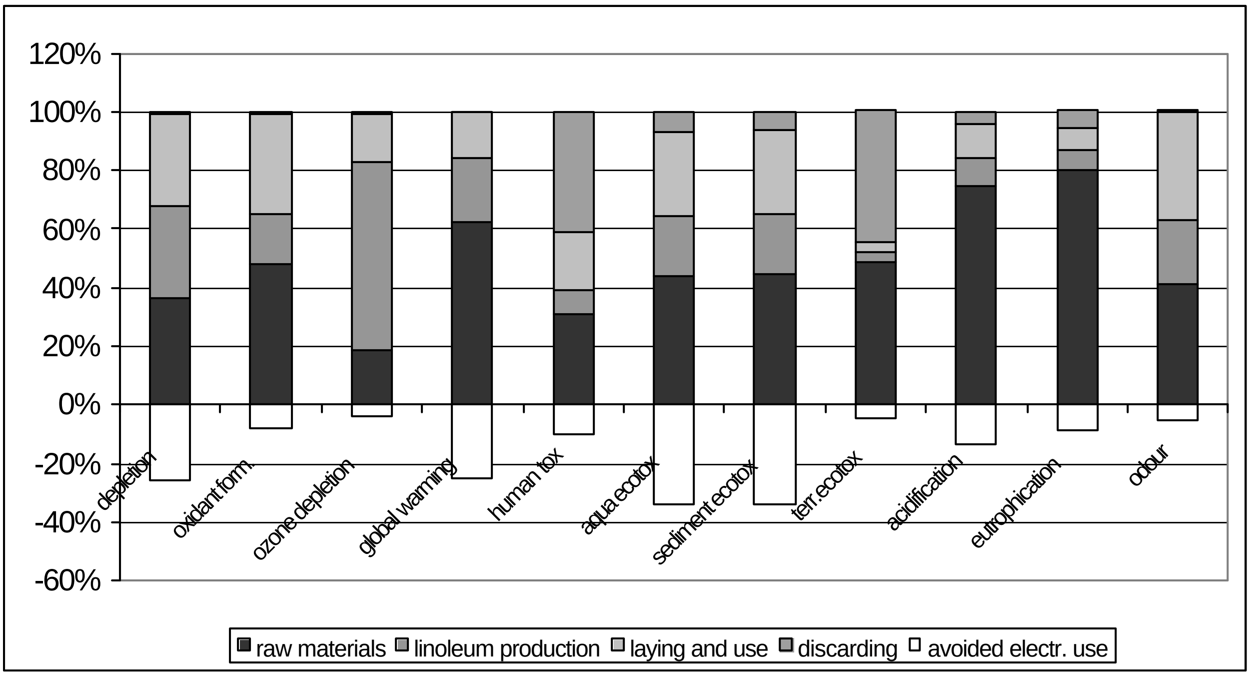


Figure 3. The contribution of life cycle stages to the category results

- The stage “raw materials “ includes all of the processes which take place for the production of raw materials (including transport) needed for the production of linoleum. These are all inputs of Forbo-Krommenie B.V. (materials and half-products), with the exception of energy carriers.
- The stage “linoleum production “ includes all of the processes taking place at Forbo-Krommenie B.V., including processes such as steam production and seaving of cork (cork-linoleum only).
- The stage “laying and use “ includes all of the processes which take place during the laying and use of the floor including transport from Forbo-Krommenie B.V. and maintenance of the floor.
- The stage “disposal “ includes transport to the waste incinerator as well as the incineration of linoleum.

It is apparent that the production of raw materials is the main contributor for most categories. Exceptions to this are the category “depletion of the ozone layer “, where linoleum production is the main contributing stage (64%) and the category “human toxicity “, where the contribution of the disposal stage is the main contributing stage (41%). For abiotic depletion, the contribution of raw materials, linoleum production, laying and use is almost equal (resp. 36%, 32% and 32%) while for “odour “, the contribution of the laying and use stages almost equals that of the raw materials stage (41% resp. 37%).

The contribution of the disposal phase is negative for most impact categories, except for human toxicity and terrestrial ecotoxicity. This is due to the “avoided emissions “, caused by the production of useful heat when the linoleum is incinerated which is then used for electricity production.

6.1.3 Processes and flows

Table 6. Main processes contributing to the environmental profile of the baseline system

impact category	processes
abiotic depletion	17% gas used by Forbo-Krommenie 15% electricity used by Forbo-Krommenie 13% oil used for the production of maintenance products (detergents and acrylic dispersions/emulsions)
Photochemical oxidant formation	25% VOC emissions due to transportation of raw material (total 44% VOC emissions during raw material production 27% VOC emissions caused by oil use during the production of maintenance products (total 32% VOC emissions during laying and use)
Depletion of the ozone layer	62% VOC emissions by the processes taking place at Forbo-Krommenie
Global warming	37% growing of linseed (mainly N2O emissions as a result of fertiliser use) 14% electricity used by Forbo-Krommenie B.V. 7% gas used by Forbo-Krommenie
Human toxicity	40% incineration of linoleum 17% VOC emissions during raw material production (10% from transportation by truck and freighter 11% VOC emissions caused by oil use during the production of maintenance products (total 13% VOC emissions during laying and use)
Aquatic Ecotoxicity	20% electricity used by Forbo-Krommenie B.V. 12% coal used for the production of detergents and acrylic dispersions/ emulsions 9% transportation of raw materials by sea freighter
Sediment ecotoxicity	19% electricity used by Forbo-Krommenie B.V. 12% coal used for the production of detergents and acrylic dispersions/ emulsions 10% transportation of raw materials by sea freighter
Ecotoxicity terrestrial	44% incineration of linoleum 37% growing of linseed
Acidification	28% growing of linseed (NH_3) 15% production of TiO2 15% transportation of raw materials by freighter and truck
Eutrophication	53% growing of linseed
Odour	21% coal used for the production of detergents and acrylic dispersions/ emulsions 18% gas used at Forbo-Krommenie 13% growing of linseed

The processes and flows that contribute most to the final results per impact category for the baseline system are described in Table 6 and Table 7. In all tables, the total of all positive contributions is set at 100%[8].

[8].This then excludes the negative contributions of avoided energy use through the production of useful heat during the incineration of linoleum.

Table 7. Main flows contributing to the environmental profile of the baseline system

impact category	flows
abiotic depletion	50% crude oil
	45% natural gas
Photochemical	32% ethylene to air
oxidant formation	18% formaldehyde to air
Depletion of the ozone layer	62% 1,1,1-trichloroethane to air
	35% HALON-1301 to air
Global warming	56% N2O to air
	41% CO2 to air
Human toxicity	34% benzene to air
	30% arsenic to air
	10% cadmium to air
Aquatic Ecotoxicity	34% vanadium to air
	32% barium to water
Sediment ecotoxicity	36% vanadium to air
	31% barium to water
Ecotoxicity terrestrial	38% mercury to air
	27% trichlorfon to soil
Acidification	53% SO_2 to air
	28% NH_3 to air
	19% NO_x to air
Eutrophication	53% NH_3
	41% NO_x
Odour	72% H_2S

Table 6 shows that a limited number of processes is responsible for the highest contributions to most impact categories. In Table 8, these main contributing processes are viewed in detail. Again, the total of all positive contributions is set at 100%. From the close resemblance between the percentages in both columns it can be seen that, for all these processes, a limited set of emissions is responsible for the high score of an impact category.
The results for “odour “ should be considered with care. The special “odour “ related to linoleum , perceptible at Forbo-Krommenie B.V. 's site, is not included in this study. Emissions of VOC during the oxidation of cement and the drying of linoleum cause this “odour “. Unfortunately, the individual VOC emissions at Forbo-Krommenie B.V. are not measured. Only the total VOC-emission is measured. Therefore, the emission of individual substances had to be estimated based on a standard emission profile which itself was based on solvent use. Apparently, this estimate does not match the real VOC mix very closely, as H2S emitted during the production of gas is cited as the main cause of “odour “ for the life cycle stage “production of linoleum “. The emissions of VOC at Forbo-Krommenie B.V. are responsible for only 2% of the total result for “odour “, which seems unlikely. Therefore, we may conclude that “odour “ is probably underestimated by using this standard emission profile.

The results for “depletion of the ozone layer “ are probably overestimated because of the use of this standard emission profile. 62% of the ozone depletion is caused by VOC-emissions from Forbo-Krommenie B.V. (see Table 6). This is entirely the result of the emission of 1,1,1-trichlorethane (see Table 7). This is a solvent which is part of the standard emission profile, but which is not used at Forbo-Krommenie B.V.

Table 8. Processes contributing more than 10% to more than one category.

process	categories the process contributes to	%	mainly caused by	%
The growing of linseed				
	eutrophication	53	NH3	53
	terrestrial ecotoxicity	37	pesticides	37
	global warming	37	N20	37
	acidification	28	NH3	28
	odour	13	NH3	13
gas and electricity use at Forbo-Krommenie B.V.				
	abiotic depletion	32	natural gas	28
	global warming	21	CO2	21
	aquatic ecotoxicity (only electr.)	20	heavy metals (mainly barium and vanadium)	18
	sediment ecotoxicity (only electr.)	19	heavy metals (mainly barium and vanadium)	19
	odour (only gas)	18	H2S	17
Oil used for the production of maintenance products				
	photo. oxidant formation	27	VOC-mix*	27
	abiotic depletion	13	crude oil	13
	human toxicity	11	VOC-mix*	11
Transportation of raw materials				
	oxidant formation	25	VOC-mix*	25
	aquatic ecotoxicity (only freighter)	9	heavy metals (mainly vanadium)	9
	sediment ecotoxicity (only freighter)	10	heavy metals (mainly vanadium)	10
	human	10	VOC-mix*	10
	acidification	15	SO2	9
Incineration of linoleum				
	terrestrial ecotoxicity	44	heavy metals (mainly mercury)	44
	human toxicity	40	heavy metals (mainly cadmium and arsenic	39
coal used for the production of detergents and acrylic dispersions/ emulsions				
	odour	21	H2S	21
	aquatic ecotoxicity	12	heavy metals (mainly barium and vanadium)	12
	sediment ecotoxicity	12	heavy metals (mainly barium and vanadium)	12

*: VOC emissions are usually given as a total the VOC-mix. However, for the impact assessment, individual substances are needed. A standard emission profile representative for stationary combustion (Hauschild & Wenzel, 1998) is used to estimate which individual substances are present in this mix (see also § 4.3.2).

Some remarks are also in order as to the high contribution of heavy metals to the categories “human toxicity “ and “ecotoxicity “. The high contribution of persistent metals is not always in accordance with the expectations based on knowledge of present toxic risk effects. This is not due to faults in the characterisation factors for heavy metals. The multimedia model used to calculate toxicity factors is based on state-of-the-art knowledge concerning the fate of substances. It is a result of a general starting point in Guinée *et al.* (2000), that being that in an LCA, all effects now and in the future are taken into account. In other words: all methods used for effect assessment, are where possible, based on a time horizon of eternity. Because heavy metals are very persistent in the environment, since they do not break down as organic substances do, their contribution to toxicity themes, especially aquatic and sediment ecotoxicity, is very high. Therefore, the results should be considered with some care. It should be kept in mind that the high score for metals is a result of taking future toxic risks into account. If these future risks are evaluated as being lower than the present risks, the contribution of persistent substances would also be lower in the future. For this study, this would mean that the influence of the more degradable but very toxic pesticides would increase relatively.

6.1.4 Important processes and the consequences of data quality

If the most important processes are known, the consequences of data quality should be considered. The main question is: Is the data which underlies these processes valid and reliable?

In the stage "production of raw materials ", the growing of linseed and transport are important processes. The growing of linseed is overall a very important process contributing greatly to more than 5 impact categories. The data for this process is valid because it is representative. Its reliability, however, may be disputed. The emissions of NH_3, N_2O and pesticides both depend largely on assumptions. The emission of NH_3 and N_2O are based on the assumption that 1 % of applied fertiliser evaporates as NH_3 and that 1% as N_2O goes into the air (Välimaa & Stadig, 1998). The emission of pesticides is based on the assumption that on 20% of the fields, one herbicide and one pesticide is used. This information is based on communications with a supplier. If these assumptions are not realistic, influences on the result may be great. Therefore, a sensitivity analysis of fertiliser and pesticide use is carried out in § 6.4.4.

In the stage "production of linoleum ", the energy used at Forbo-Krommenie B.V. is most important. We expect that this data is valid and reliable. Therefore, these processes are not analysed further in the sensitivity analysis.

In the stage "laying and use ", the coal and oil used during the production of maintenance products is important. Data on the production of maintenance products is not complete. Therefore, in the scenario analysis, maintenance options are analysed in greater depth (see § 6.4.1).

In the stage "disposal ", the emissions produced during incineration are important. However, the figure of 100% incineration of used linoleum and the linoleum waste from Forbo-Krommenie B.V., is only an assumption. Therefore,a sensitivity analysis has been carried out in which the waste is not incinerated but landfilled (see 6.4.3) .

6.2 Comparison with previous LCA-studies on linoleum

The comparison of the results from this study with those of other studies on linoleum floor coverings, serves as a first validity check of the total results for the baseline system.

Three other LCA-studies on linoleum floorings were known at the time this report was being written:

- Potting & Blok carried out an LCA-study, in which four different types of floor covering including linoleum were compared (Potting & Blok, 1993, 1995).
- Jönsson *et al.* (1995) carried out an LCA-study in which three different types of floor covering including linoleum were compared. However, they did not calculate the contributions to impact categories but , rather compared the alternatives chiefly on the basis of inventory data. A large part of the data they used was based on Potting and Blok (1993).
- Günther and Langowski (1997) carried out an LCA-study, in which seven different types of floor covering, including linoleum, were compared. However, from this most recent study, only very few results for linoleum are presented. No information concerning the contribution of processes or stages

is presented, only the total results of the whole life cycle of linoleum are presented and compared to other floor coverings. Also, only a small selection of impact assessment categories is presented (no human toxicity or ecotoxicity, no oxidant formation, no “odour “). This makes the results of this study less useful for comparison.

Below, the results of our study are, where possible, compared to results from other LCA-studies. If a study is not mentioned, no data were available on the subject in question.

6.2.1 Abiotic depletion

In this study, the contribution of raw material production is the highest (36%), followed by the contribution of linoleum laying and use (32%), and production of linoleum (32%). However, the main contributing processes are the use of electricity and gas at Forbo-Krommenie B.V.

Potting & Blok (1993, 1995) state that of the use of primal energy carriers (≈ abiotic depletion) 66% is required for linoleum production and 20% for the production of pigment (TiO2). In the study of Jöhnsson *et al.* (1995), linoleum production is also responsible for the major portion of electricity use of and for the use of fossil fuels (respectively 44% and 67%). Also, in their study, the electricity used for the production of TiO2 is high: 30%.

The higher contribution of the other stages - raw material production and laying and use - in our study can be explained by two factors:

- The estimate of the energy used at Forbo-Krommenie B.V. in this study is lower than that which appears in other studies. In this study, the electricity used at Forbo-Krommenie per 1 m^2 laid linoleum is approximately 8 MJ. Potting and Blok give a value of 15 MJ and Jöhnsson *et al.* 16 MJ.
- In our study, we gathered more data, especially on the laying and use phase.

Likewise, the contribution of the production and transport of TiO2 is much lower (only 5%) in our study. We used other data on the production of TiO2 than Potting & Blok and Jöhnsson. According to the supplier of our data on TiO2, the production of TiO2 has a relatively low energy need (pers. comm. Dr. Saur, PE).

6.2.2 Eutrophication

In this study, the growing of linseed is responsible for 53% of eutrophication. This is in accordance with Potting and Blok, who state that the eutrophication result is almost completely caused by the growing of linseed.

6.2.3 Acidification

In this study, 28% of the acidification is caused by the growing of linseed, 15% by the production of TiO2 and 15% by the transport of raw materials. Potting and Blok state that 44% is caused by transport (a figure which includes the transport of raw materials only) and 30% by the production of linoleum. Jöhnsson *et al.* state that the emissions of SO and NO_x are caused for a great part by transport (62% and 31%).

One explanation for the high contribution of linseed growing in our study is the assumption that 1% of the applied N-fertiliser evaporates as NH_3. In the other studies, no emissions of NH_3 are produced as no emission of NH_3 is found in the inventory tables.

6.2.4 Photochemical oxidant formation

In this study 27% of the photochemical oxidant formation is caused by VOC emissions resulting from oil use when producing maintenance products, and 25% is caused by VOC emissions resulting from transport by truck and freighter.

Potting and Blok found that 70% was caused by the VOC emission during the production of linoleum, and 15% by the incineration of linoleum. Jöhnsson *et al.* also found that 87% of the VOC emissions are a result of linoleum production, however, they based their data mainly on Potting and Blok.

In our study, the contribution of linoleum production to total VOC emissions is only 22%. The total amount of VOC emitted per m^2 laid linoleum by the factory at Krommenie issomewhat lower (2 g) in our study than in those of Potting and Blok, and Jöhnsson (both 5 g). However, the total emitted amount is higher in our study: 19 g in our study, 7 g in Potting and Blok and 6 g in Jöhnsson respectively.

Since our data on VOC emissions comes directly from Forbo-Krommenie B.V., while the data presented in other studies comes mainly from the environmental permits, our data is more realistic. Also, the data on the other stages in our study appears to be more complete.

6.2.5 Depletion of the ozone layer

In this study, we recorded a relatively low score for ozone depletion compared to the other impact categories. Potting and Blok, and Jöhnsson *et al.* assumed no ozone depleting emissions.

6.2.6 Global warming

In this study, we found that 37% of the global warming is caused by the growing of linseed and 21% by the use of electricity and gas during linoleum production.

Potting and Blok found that 66% was caused by the production of linoleum and 20% by the production of pigment (TiO2). Also in Jöhnsson *et al.* linoleum production was responsible for 58% of CO_2 emissions.

One explanation for the high contribution of linseed growing in our study is the assumption that 1% of the applied N-fertiliser evaporates as N_2O. In the other studies, no emissions of N_2O take place (no emission of N_2O are found in the inventory tables). The contribution of the production of TiO2 in our study is only 4%.

6.2.7 Ecotoxicity

In this study, we found a relatively high contribution for ecotoxicity. Potting and Blok, and Jöhnsson *et al.* found almost no emissions to water. Potting and Blok mention the use of pesticides for the growing of linseed, but were not able to quantify the emissions.

6.2.8 Human Toxicity

In this study, human toxicity is mainly caused by emissions of heavy metals and benzene as a result of the incineration of linoleum as well as of VOC emissions which occur during the production of raw materials. Potting and Blok present an impact category “spoiled air “ (≈ human toxicity by air emission). The result for this category is mainly caused by the emission of dust during production of limestone. They also mention that the contribution of pesticides could not be quantified properly, but is probably considerable.In our study, however, the influence of pesticide use on human toxicity is relatively low (<1%).

6.2.9 Odour

Odour is not mentioned in other studies, so no comparison could be made.

6.2.10 Conclusions

When compared with the other studies, more data was compiled here on life cycle stages, such as raw material production, use and maintenance (e.g. emissions which ocuur during the production of linseed or in the production of maintenance products). This resulted in a relatively large contribution of these life cycle stages to the final environmental profile. However, it should be kept in mind that these data were not validated or made public.

Furthermore, we used emission data directly provide by Forbo-Krommenie B.V. These values were lower than the values from the environmental permit for the factory in Assendelft which were used in the other studies. The lower values are the result of improvements made by Forbo-Krommenie B.V. after the submission of the permit. For instance, lacquers with less solvents are now used and more VOCs are removed by the incinerators. The data provided by Forbo-Krommenie B.V. is more realistic and, therefore, the lower contribution of the lifecycle stage “production of linoleum “ is also more realistic than that offered in the other studies. This data is amongst others reported in environmental reports and in reports by Central Statistics Netherlands.

6.3 Perturbation analysis

In the perturbation analysis, the influence of a variation in each economic flow on the final result is calculated using matrix techniques. This may provide insight into which processes have a more than proportional effect on the end result. These processes could then become the focal point for further sensitivity analysis. In table 2, the results of the perturbation analysis are presented. The factor is the ratio between the change in the flow and the change in the result. If this factor is higher than 1 for a given flow, this means that a change in the flow concerned results in a more than proportional change in the result.

Table 9 shows that “laid linoleum “ is the most important economic flow for all impact categories. For global warming, and aquatic and sediment ecotoxicity, a change in this flow results in a more than 10% higher change in the final category result. However, since this economic flow (2000m^2) is directly coupled to the functional unit (2000m^2·20 years), there is no uncertainty concerning this flow. Therefore, the flow is not evaluated in the uncertainty analysis based on scenarios in § 6.4. It is concluded that no environmental flow has more than a proportional effect on the final results per impact category.

Table 9. perturbation analysis

category	economic flow	ratio change flow/ change	environmental flow	ratio change flow/ change

		result		result
abiotic depletion	laid linoleum	1.03	none above 1	-
photo. oxidant formation	none above 1	-	none above 1	-
depletion of the ozone layer	none above 1	-	none above 1	-
global warming	laid linoleum	1.18	none above 1	-
	2.5 mm linoleum packed	1.09		
	2.5 mm linoleum trimmed	1.06		
	2.5 mm linoleum dried	1.03		
human toxicity	none above 1	-	none above 1	-
aquatic ecotoxicity	laid linoleum	1.12	none above 1	-
sediment ecotoxicity	laid linoleum	1.12	none above 1	-
terrestrial ecotoxicity	none above 1	-	none above 1	-
acidification	laid linoleum	1.02	none above 1	-
eutrophication	none above 1	-	none above 1	-
odour	none above 1	-	none above 1	-

6.4 Scenarios

Scenario analysis is used to verify what percentage of the results for the baseline system is influenced by differences in system, processes or process data, or by differences in methods.

6.4.1 Alternative systems/countries

In § 3.4, we defined two functionally equivalent alternatives along with the baseline system. One of these systems is the Swedish system. Analysing this system provides insight into the effects of different maintenance systems, different gauges and different transportation distances for the linoleum. To evaluate the influence of transportation distances, the USA scenario is introduced.

In Figure 4, the results for three alternative scenarios related to the country of use are presented.

- The Swedish scenario: in Sweden, a thinner gauge of 2.0 mm is frequently used in public buildings. Because of the different climate in Sweden, a different maintenance system is also used. This system is based on wax rather than on stripping and on adding a new polymer top layer as is the case in the Netherlands.
- The 2.0 mm system NL is the 2.0 mm gauge used in the Netherlands, using the Dutch maintenance system.
- The scenario for the US is the same as the baseline system, with an additional transport distance (transport to and in the USA).

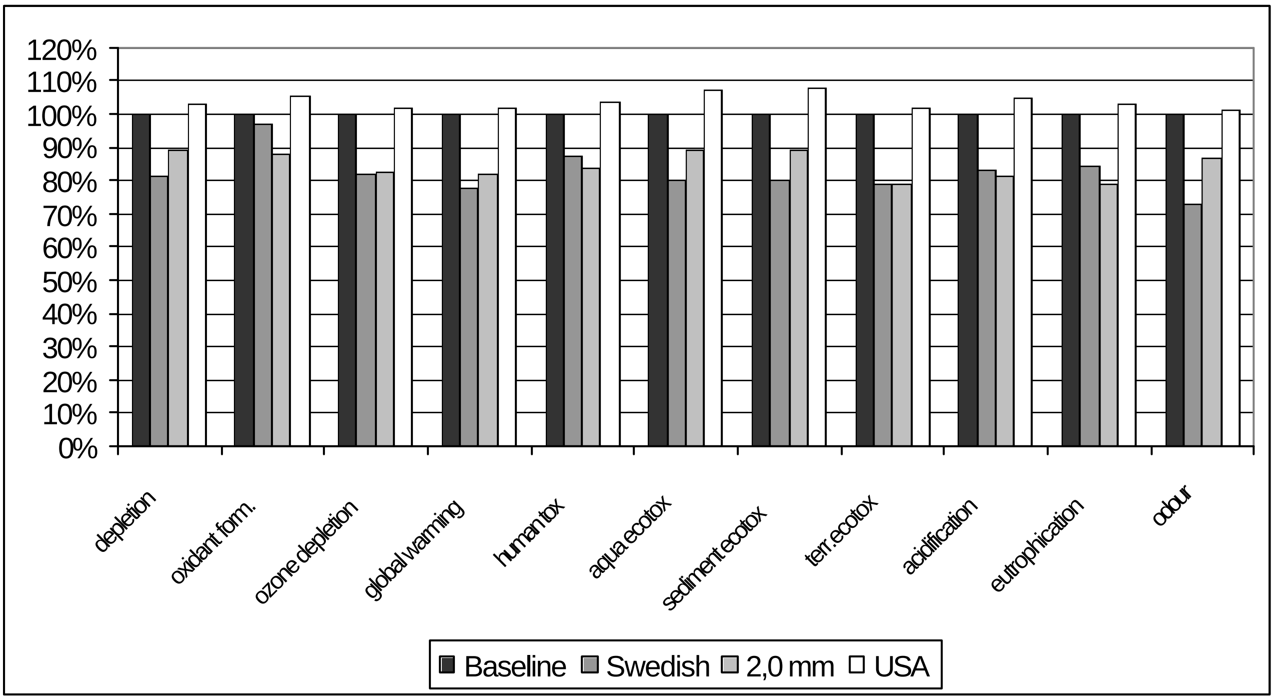


Figure 4 . Environmental profile for the baseline system and three alternative scenarios related to the country of use.

This figure would indicate that despite the longer transportation distances, the Swedish system yields lower results (3-27%) than the baseline. This is caused by the lower contribution of the Swedish maintenance system and the fact that less material is needed for the gauge 2.0 mm. However, the lower contribution of the Swedish maintenance system is at least partly the result of lack of data. Data on the emissions and use of energy during the production of maintenance products is less complete than for the Dutch system.

The 2.0 mm gauge used in the Netherlands scores lower for oxidant formation, human toxicity, terrestrial ecotoxicity, acidification and eutrophication. For the other categories, however, it scores higher than the

Swedish scenario. This means that maintenance has more influence than transportation distance for those categories. It appears that the environmental profile (the list of the results for all impact categories) for the Swedish maintenance system is indeed 80-90% lower than for the Dutch maintenance system.

This is at least partly a result of data gaps for the production of maintenance products for the Swedish method. It followed from the contribution analysis that the oil and coal consumed during the production of maintenance products contributes considerably to human toxicity, ecotoxicity, abiotic depletion and photo oxidant formation. Although the validity and reliability of the ETH data used for these processes can be questioned, it at least indicates that the contribution of the production processes for maintenance products are not negligible. Based on this study, no other conclusions can be drawn concerning the difference between Dutch and Swedish maintenance systems.

The results for the USA scenario are higher for every impact category, however, not much higher. The maximal increase in ecotoxicity was found in sediment ecotoxicity, which was 8% higher for the USA scenario as compared to the baseline scenario.

Conclusion :

- The extra transport by freighter to the USA has less impact than was expected.
- The influence of maintenance is not negligible, as is often thought.

6.4.2 Alternative systems/products and ingredients

In § 3.4, we defined two functionally equivalent alternatives in addition to the baseline system. Along with the Swedish system, the system producing cork linoleum was defined. To analyse the influence of different ingredients and product types more thoroughly some other linoleum types have been analysed, as well as the cork linoleum. In Figure 5, five different scenarios related to differences in ingredients are shown.

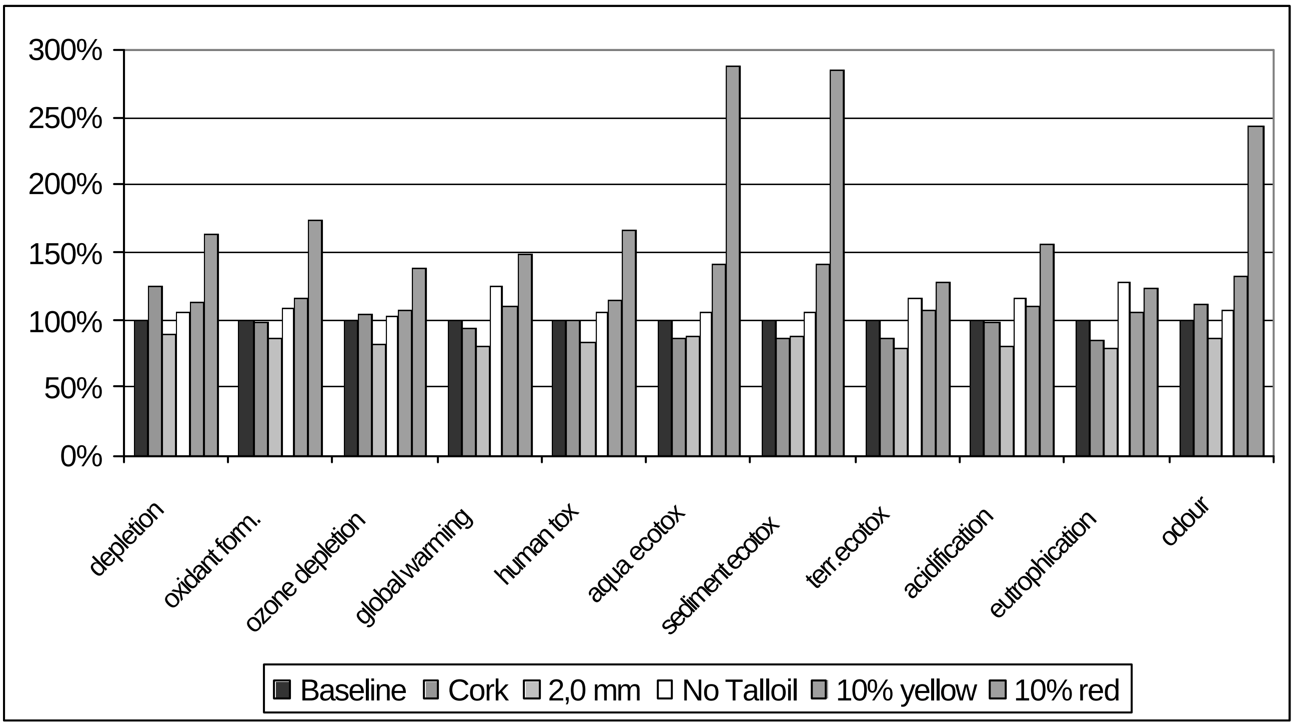


Figure 5. Environmental profile for the baseline system and five alternative scenarios related to differences in ingredients.

- The cork-linoleum is based on 4.5 mm cork linoleum. In the production of cork linoleum, cork powder is used instead of wood flour. This cork powder is first sieved at Forbo-Krommenie B.V. The composition of this linoleum also differs from normal Marmoleum.
- The 2.0 mm gauge used in the Netherlands was already described above.
- "No tall oil " linoleum receipt is made without tall oil.
- "10% yellow and 10% red " are scenarios in which 10% of the TiO2 is replaced by respectively yellow and red organic pigments. In the linoleum produced by Forbo-Krommenie B.V., an average 16% of the pigment consists of pigment other than TiO2. 12% consists of iron oxides and 4% of organic pigment (source: Forbo-Krommenie B.V.). thus, 10% organic pigments is approximately twice as high as the actual amount of organic pigments, but lower than the total amount of "alternative " pigments.

The environmental profile of cork-linoleum shows lower results for most impact categories than the baseline scenario. This decrease varies from 1 to 13% (for the ecotoxicity categories). This decrease is mainly the result of using fewer materials in addition to cork (relatively more cork is used than wood powder) which also results in a reduction in the use of electricity during raw material production, and of linseed. However, the results for the impact categories "abiotic depletion ", "odour " and "depletion of the ozone layer " are respectively 25%, 13% and 3% higher than those in the baseline scenario. For "abiotic depletion " and "odour " this is mainly the result of a high use of gas during the milling and drying of cork, and for "depletion of the ozone layer "of an increase in the VOC emissions from the production site in Assendelft (9% higher).

The environmental profile of the 2.0 mm linoleum gauge shows, on average, a ±15% lower result for all impact categories. This is due to less material use and less waste production.

The environmental profile of 2.5 mm linoleum without tall oil shows, on average, a ±15% higher result for all impact categories. The maximal increases for the categories "eutrophication " (28%) and "global warming " (25%), are mainly caused by a 40% higher use of linseed.

The environmental profile of the 2.5 mm linoleum with 10% yellow pigment shows, on average, a ±15% higher result for all impact categories. The maximal increases are in the categories "aquatic ecotoxicity " and "sediment ecotoxicity " (41%) and "odour " 31%. The environmental profile of the 2.5 mm linoleum with 10% red pigment shows, on average, a ± 80% higher result for all impact categories. The maximal increases here are for the categories "aquatic ecotoxicity " and "sediment ecotoxicity " (± 280%) and "odour " ± 240%. It appears that the environmental profile for 1 kg yellow and red pigment is approximately 2500 respectively, 1000 times higher than the profile for the white pigment TiO2. Among other factors, this is caused by the greater energy consumption of yellow and red pigment. From this it may be concluded that TiO2 is not representative for other pigments and that the impact of other pigments should be included in future LCA-studies on linoleum.

Conclusion:

- The influence of pigments other than TiO2 can be considerable. TiO2 is not representative for other pigments. The impact of other pigments may also be high, although their share in the product is much lower.
- Using tall oil in the linoleum is better for the environment than using only linseed oil and gum rosin.
- Using 2.0 mm linoleum is better for the environment. However, this is only the case if the life span of the 2.0 mm linoleum is more or less the same as that of the 2.5 mm gauge.

6.4.3 Alternative allocation methods/waste

Data on the treatment of waste depends for a large part, on assumptions. It is assumed, for example, that all old linoleum and all linoleum waste from Forbo-Krommenie B.V. is incinerated. It is also assumed that electricity is produced just as it is assumed that the efficiency is 40%. To analyse the effect of these assumptions, we used a few scenarios in which waste treatment is varied.

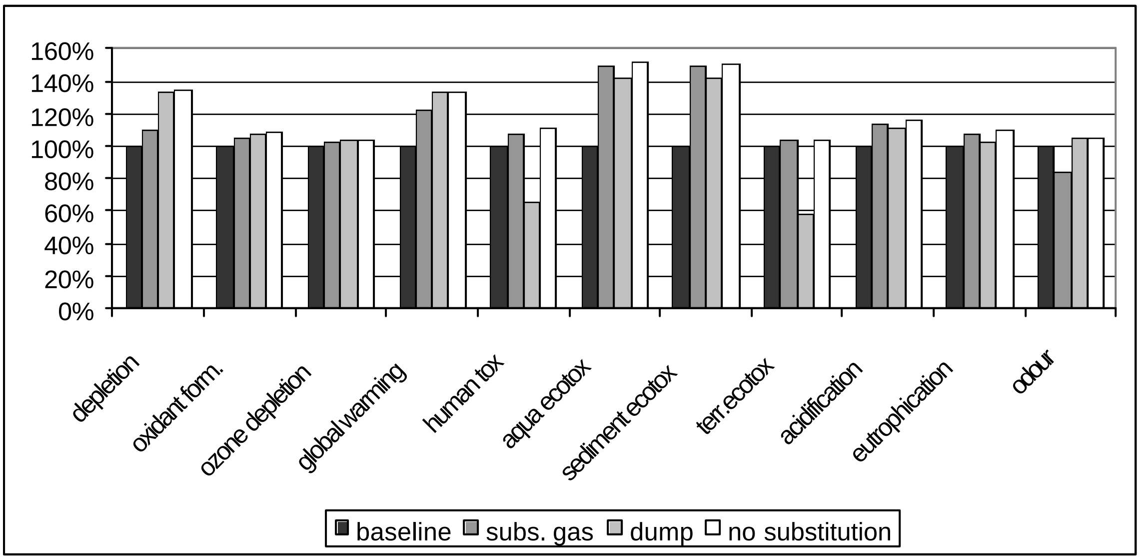


Figure 6. Environmental profile for the baseline system and three different scenarios related to handling linoleum waste

In Figure 6, three different scenarios related to handling linoleum waste are shown.

- The first scenario is an alternative allocation method for the heat produced by theincineration of linoleum. It is assumed in this scenario that the heat is used for heating (e.g. city heating) Heat is, therefore, replaced with avoided gas use.
- The second scenario is based on dumping the linoleum in a landfill site, rather than incinerating it.
- The third scenario is an alternative allocation method for the heat produced by the incineration of linoleum. Instead of the substitution method the surplus method is used, which means that the produced is not used and that no inputs or outputs are allocated to this flow.

Figure 6 shows that the allocation method chosen for the baseline received the lowest score for virtually every impact category. Substitution of gas use for electricity use results in a 15% lower score for "odour " and a higher score for all other impact categories. Dumping the waste on a landfill site results in a substantial lower score for human toxicity (34% lower) and terrestrial ecotoxicity (42% lower), this, however, is not surprising since in both categories, emissions resulting from the incineration of linoleum cause the highest score. For all other categories, the results are higher. Not surprisingly, the scenario in which the heat produced is not used, shows the highest results for all impact categories.

6.4.4 Alternative data/miscellaneous

In Table 10, some scenarios related to input data are presented.

- Because the growing of linseed is an important process and because data is partially based on assumptions (see discussions on data quality in § 4.3.1and 6.1.4), three different scenarios concerning pesticide emissions and N-emission were evaluated.
    - The scenario is based on the assumption that all pesticides that could be used according to the supplier are indeed used on every hectare, in the prescribed dose. Since the suppliers also indicated that on only approx. 20% of the fields a pesticide is used, and that at no time are all pesticides used at the same field, this represents the worse possible scenario.
    - The scenario based on the absence of pesticide use.
    - The scenario based on a lower use of N-fertiliser (0.04 kg N per kg linseed instead of 0.068 ≈ the amount taken up yearly by the linseed)

- Given the low score of the VOC-emissions at Forbo-Krommenie B.V. in relation to the H2S score on the impact category “odour “ an alternative scenario was evaluated assuming all emitted VOC were butanal (“ “that is, having a relatively high “odour “ factor).
- In order to ascertain whether shorter transportation distances for the raw materials would yield a substantially lower environmental profile, a scenario was analysed based on a 50% lower transportation distance per barge, for all raw materials.

Table 10. Environmental profiles for various scenarios with alternative input data, relative to the baseline system (in %).

	high pesticide	no pesticide	lower use of N-fertiliser	all VOC at Forbo-Krommenie B.V. = butanal	50% shorter transportation by freighter
Depletion of abiotic resources	102	100	97	nr	98
Photochemical oxidant formation	104	100	98	nr	98
Depletion of the ozone layer	101	100	99	nr	99
Global warming	101	100	76	nr	99
Human toxicity	105	100	98	nr	98
Aquatic ecotoxicity	102	100	95	nr	93
Sediment ecotoxicity	102	100	95	nr	93
Terrestrial ecotoxicity	162	61	99	nr	99
Acidification	101	100	85	nr	96
Eutrophication	102	100	74	nr	98
Odour	101	100	91	2100	99

nr = not relevant

The “high pesticide use “ scenario shows mainly a higher score in the category “terrestrial ecotoxicity “. The effect on human toxicity is relatively low (only a 5% increase), which is in accordance with the observation made above concerning the relatively low contribution of pesticide emissions to human toxicity. The effect on aquatic and sediment toxicity is still not very high. The effect of heavy metals continues to dominate these impact categories. Not surprisingly, the “no pesticide use “ scenario shows the opposite effect. The impact category “terrestrial toxicity “ shows a decrease of 39% while the other categories show no decrease.

The “lower use of N-fertiliser “ scenario shows lower results for every impact category. Global warming, acidification and eutrophication show a decrease of 15-26%. The influence on the other categories is lower.

The replacement of all VOC-emissions by butanal (hence a worse case estimate for “odour “) leads to an increase in the result for the impact category “odour “ by a factor of 21. In this scenario, 95% of the score for “odour “ is caused by the VOC-emissions at Forbo-Krommenie B.V. Thus, assumptions concerning the composition of the VOC emissions at Forbo-Krommenie B.V.have a considerable influence on the category “odour “.

The scenario in which transport by sea-freighter is halved shows slightly lower results for all impact categories. The greatest decrease is seen in the category “ecotoxicity “ for water and sediment (7%).

Conclusions:

- Reduction of pesticides only effects terrestrial ecotoxicity, and not the other toxicity categories.
- Reduction in the use of N-fertiliser mostly effects the results for global warming, eutrophication and acidification.
- If the assumption that 1% of the applied N evaporates as NH_3 and 1% as N_2O is not realistic, but rather too high, the results for global warming, eutrophication and acidification are overestimated.

- Reduction in the transportation distance for raw materials has some effect on aquatic and sediment ecotoxicity.
- Assumptions concerning the composition of VOC emissions at Forbo-Krommenie B.V. have a considerable influence on the category “odour “. A better estimate of the composition of these emissions is necessary in order to assess the effects on “odour “ properly in an LCA on linoleum products.

6.4.5 Alternative impact assessment methods

NB! The methods used in this section are not in accordance with ISO standards and guidelines, as weighting is performed, and methods combining characterisation and weighting as one step are used.

In addition to the CML-2000 method (Guinée *et al.*, 2000) which is followed in this study, there are a number of other methods for impact assessment in LCA. Some of these methods follow more or less the same structure as the CML-method in that they first calculate results per impact category by multiplying the emissions/extractions with characterisation factors. These results per impact category can then possibly be weighted and summed to such an indicator as Ecoindicator 95: Goedkoop, 1995. Yet other methods use factors which combine the characterisation and weighting step in one, resulting directly in one final value (e.g. EPS: Steen, 1996; Ecoscarcity: Ahbe *et al.*, 1990, Baumann, 1992; ExternE: EC, 1995).

A few of those alternative methods are applied to the baseline scenario in order to determine how dependent the results are on the method used. The additional methods we used are:

- The Ecoindicator 95 (Goedkoop, 1995).
- ExternE (EC, 1995).
- EPS (Steen, 1996).
- Swiss Ecoscarcity (Ahbe *et al.*, 1990).
- Norwegian Ecoscarcity (Baumann, 1992).

The ecoindicator is comparable to CML-2000, in that characterisation, normalisation and weighting are done in separate steps. Therefore, the contribution of the different life cycle stages to the individual impact categories could be visualised and compared to the unweighted results for the CML-2000 method. For the other methods, characterisation and weighting are combined in one step to yield one weighted total result. Therefore, a comparison of these methods with the CML-2000 method was only possible when the results per impact category for the CML-2000 method were also weighted. Hence, we applied an equal weighting to all categories (counting ecotoxicity as one category), resulting in Figure 8 and Table 11.

In
Figure 7 the results calculated with the Ecoindicator 95 are presented. When this figure is compared with Figure 3, it becomes apparent that the results for impact categories, which are part of both methods, are very similar. However, the Ecoindicator has a different way of dealing with toxic substances. Their categories i.e. “heavy metals “, “pesticides “, “carcinogenic substances “, are grouped according to substance characteristic/effect type, while the CML-method is more focused on such endpoints as risk to ecosystems and risk to humans[9]. When all categories are weighted and summed, the most important impact category is heavy metals, which accounts for 75% of the total positive score (excl. negative value of linoleum incineration). If one were to use equal weights for every impact category, “sediment ecotoxicity “ would be the most important impact category for the CML-method (67%), attributable largely to heavy metals. However, the high contribution of heavy metals to ecotoxicity in the CML-2000 method should be considered with some care, as was discussed above see (§ 6.1.3).

[9] in the new version of the ecoindicator, the ecoindicator 99 the impact categories are defined even more at endpoint level than in the CML-method: human health, ecosystem quality and resources. However, this method was not available yet at the moment the database of CMLCA was set up.

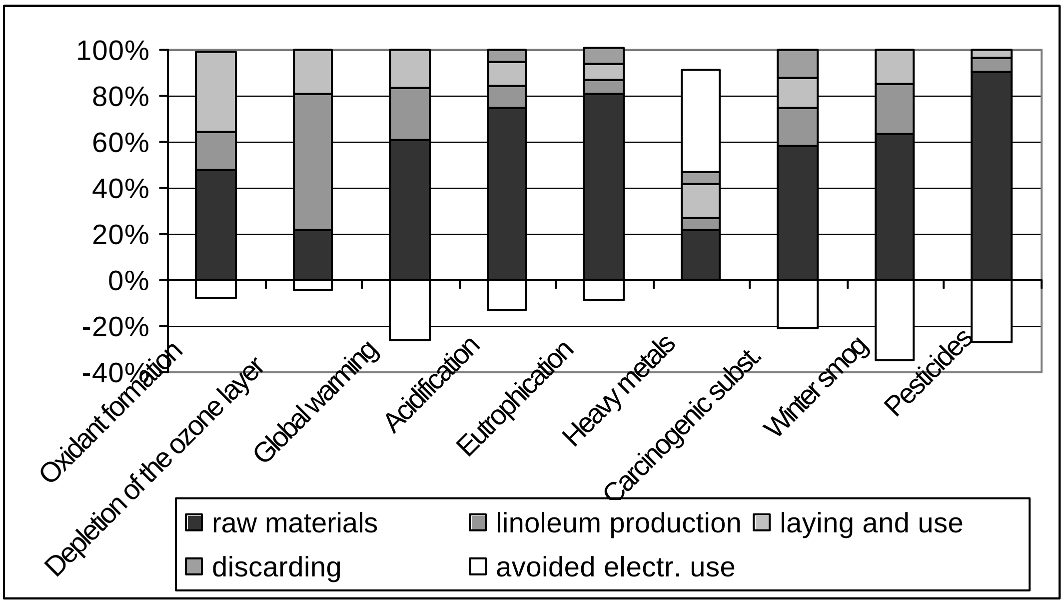


Figure 7. Environmental profile of the baseline system calculated with the Ecoindicator 95, split-up into life cycle stages.

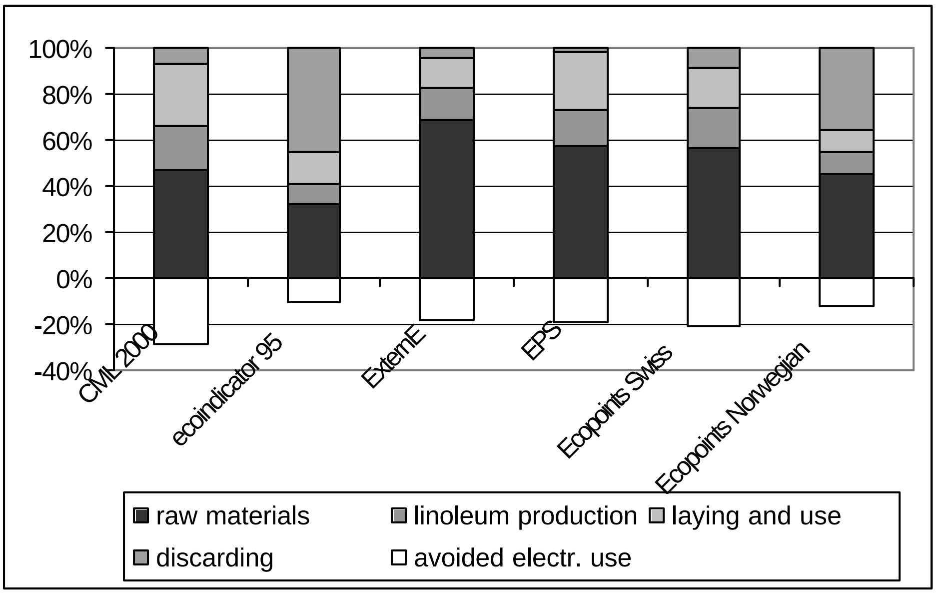


Figure 8. Total weighted results for the baseline system calculated with different methods.

In Figure 8, the results calculated with the methods combining characterisation and weighting in one step are compared with the weighted results for the Ecoindicator 95 and the CML 2000 method, using the arbitrary weighting factor of 1 for each impact category (except the ecotoxicity categories, which were first averaged and the average result was then weighted with a factor of 1). All methods indicate the raw material stage as the most important, with the exception of the Ecoindicator 95 which rates the disposal stage the highest.

Table 11. Main contributing processes to the total positive weighted results for a number of impact assessment methods (excluding the negative result of incinerating linoleum).

IA method	main contributing process	
CML 2000	electricity used by Forbo-Krommenie B.V.	16%
Ecoindicator 95	incineration of linoleum	45%
ExternE	growing of linseed	19%
EPS	growing of linseed	17%
Swiss Ecoscarcity	production of TiO2	13%
Norwegian Ecoscarcity	incineration of linoleum	36%

Table 12. Main contributing environmental flows to the total weighted results for a number of impact assessment methods

IA method	main contributing flows (emissions/ extractions)	
CML 2000	Vanadium to air (V)	28%
	Barium to water (Ba)	24%
Ecoindicator 95	Cadmium to air (Cd)	25%
	Lead to air (Pb)	13%
ExternE	Sulfur dioxide to air (SO_2)	38%
	Nitrogen oxide to air (NO_x)	24%
EPS	Crude oil (resource)	26%
	Carbon dioxide to air (CO_2)	24%
Swiss Ecoscarcity	Nitrogen oxide to air (NO_x)	47%
	Sulfur dioxide to air (SO_2)	29%
Norwegian Ecoscarcity	Mercury to air (Hg)	25%
	Nickel to air (Ni)	24%

In Table 11 and Table 12 the most important processes and emissions/extractions per impact assessment method are presented. Although most methods agree on the raw materials stage as being the stage that contributes most to the total weighted result, the main contributing processes and flows vary. The methods can be divided roughly into three groups, namely a group which places high values on metals (CML 2000, Ecoindicator 95, Norwegian Ecoscarcity), a group which places high values on acidifying substances (ExternE, Swiss Ecoscarcity), and a group (the EPS method) in which the crude oil resource and CO_2 play the most important role.

Since all methods give different end results for the baseline scenario, the question: "which method should be used? ", becomes an important one. The methods combining characterisation and weighting have one major disadvantage: characterisation and weighting cannot be separated and, therefore, value choices are more implicit than in the methods where the two steps are separated. Because of this combined step, these methods are likewise not compatible with the ISO framework (ISO 14042, 1999). In the ISO framework, the environmental profile resulting from classification and characterisation is an important result on its own, and the more value-based weighting procedures are clearly a separate optional element (ISO 14042, 1999). Doing the analysis in two steps leads to greater transparency. It makes it possible to analyse the data more thoroughly by providing more information on the types of environmental impacts that can be expected. Moreover, combined methods often work with much smaller sets of factors. The EPS, ExternE and Ecoscarcity methods used in this study, use sets of 10 to <70 different factors, whereas both the CML 2000 method and the Ecoindicator 95 have more than 1000 factors. Therefore, we advise using a two step method and because the factors from the CML 2000 method are more up to date than those of the Ecoindicator 95, we advise using the results from the CML 2000 method[10]

[10] In future LCA studies, the Ecoindicator 99 might well be a valuable addition to the CML 2000 method for Forbo-Krommie BV.

6.5 Data gaps

Two major data gaps play an important role in this study. In § 4.2, the system boundaries are defined. Capital goods were deliberately excluded from the system. In § 4.3, the main data gaps for processes within the system boundaries are identified. These data gaps are for the most part chemicals. To give a rough estimate of the effects of excluding these two types of data, we used a very rough estimate for both the production of capital goods and chemicals.

The inputs and outputs resulting from capital goods are estimated using a database from the Carnegie Mellon University (Pittsburgh, USA). This database is accessible at the internet site (www.eiolca.net), on which the global results of an input/output database per dollar production per sector per year are presented. We included input/output data on the production of “General industrial machinery and equipment , n.e.c. “ in our study, assuming that 10% of the yearly turnover of Forbo-Krommenie B.V. is invested in capital goods. This is, of course, a very rough estimate. This database is not complete and given in the database could be included in our inventory (for instance, toxic emissions are given in total emissions to water, air and soil, rather than in individual substances). However, including these data in the baseline system can yield a rough impression of the contribution of capital goods for linoleum production.

The inputs and outputs resulting from unknown chemical production are estimated based on data on the production of organic chemicals in the ETH-database. This is also a very rough estimate. This data is probably not entirely representative for the missing chemicals and the reliability of the data on this general organic chemical will not be very high. Not all chemicals for which data was unavailable will be organic chemicals. However, the emissions for organic chemicals in the ETH-database are higher than for the inorganic chemicals, hence choosing the organic chemical yields a sort of worse case estimate.

In Table 13, the characterisation results for the baseline system, including estimates for capital goods and missing chemicals, are presented. It is apparent that including those estimates leads to an increase of approximately 40% for aquatic and sediment toxicity and global warming as well as to an increase of approximately 20% for abiotic depletion, photo oxidant formation, global warming and acidification. The rise in the toxicity results is caused completely by the addition of data on chemicals. This is not surprising since the emission data on toxic substances from the Carnegie Mellon database could not be included in this study. The highest rise caused by capital goods is the 10% rise of the global warming score.

Conclusions:
The influence of capital goods on the environmental performance of Forbo-Krommenie B.V. is not negligible. According to this rough estimate, leaving out capital goods may lead to an underestimation of 1-10% per impact category. The influence of the missing chemicals could even be higher. According to this rough estimate these data gaps may lead to an underestimation of 5-40% per impact category.

Table 13. Characterisation results for the baseline system including estimates for capital goods and missing chemicals, relative to the baseline system (in %).

	addition of missing chemicals	addition of capital goods	addition of missing chemicals and capital goods
Depletion of abiotic resources	114	105	118
Photochem. oxidant formation	113	107	119
Depletion of the ozone layer	107	102	109
Global warming	112	110	122

Human toxicity	110	103	113
Aquatic ecotoxicity	138	100	138
Sediment ecotoxicity	138	100	138
Terrestrial ecotoxicity	106	100	106
Acidification	116	106	122
Eutrophication	104	104	108
Odour	105	101	105

6.6 Data quality and applicability

Combining the results from the contribution analysis with the knowledge on the quality of the data the following conclusions may be drawn :

- Data on the growing of linseed is partially based on assumptions. Because this process has a large influence on the outcome of the study (see § 6.1.3 and the scenarios in § 6.4.4), it is advisable to try to ground these assumptions with better data.
- Better data on maintenance products is needed. The results of the comparison of the Dutch and Swedish scenario are influenced by a lack of data on the production of Swedish maintenance products (see scenarios in § 6.4.1). Therefore, no conclusions can be based on the comparison of these maintenance systems, other than that maintenance is not negligible.
- Because the data on red an yellow pigments comes from personal communications only, a quality check was not possible. However, inclusion of this data did show that its influence can be considerable (see scenarios in § 6.4.2).
- The estimate of the composition of VOC emissions at Forbo-Krommenie B.V. is not very realistic. As a consequence, the result for "depletion of the ozone layer " is overestimated and the result for "odour " is underestimated (see scenario in § 6.4.4 and the discussion on "depletion of the ozone layer " in § 6.1.3, Table 6 and Table 8). These results are therefore, less reliable.
- The use of average data for the landfilling process is not very representative for the effects of dumped linoleum. However only a small fraction of the linoleum is supposed to be dumped. Moreover the contribution of the process landfilling is not important for any of the impact categories. So the use of these average data probably does not have a high influence on the result of this study.
- Because the linseed straw was not included in the study (see § 4.2), the emissions of the burning of this straw other than CO_2 are not included in this study. This might result in an underestimation of the contribution of the process " growing of linseed " which is already a very important contributing process.
- According to a very rough estimate leaving out capital goods may lead to an underestimation of 1-10% per impact category (see scenario in § 6.5).
- The influence of the missing chemicals (mainly in maintenance products, lacquers and adhesives) on the environmental profile could be even more substantial. According to a very rough estimate, these data gaps may lead to an underestimation of 5-40% per impact category (see scenario in § 6.5).

Based on these conclusions we would state that:

- The results of the study are applicable for analysis of the described systems only. This means that:
  - The results should not be used to compare the environmental performance of linoleum produced by Forbo-Krommenie B.V. to other products.
  - The results should not be used to compare systems with different capital goods because capital goods are not included.
  - The results should not be used to compare different maintenance systems because too much data on chemicals in maintenance products is missing.
- The results for "odour " and "depletion of the ozone layer " should be presented with some care as the unreliable VOC estimations at Forbo-Krommenie B.V. play an important role in these impact categories.

7 Conclusions and discussion

In this chapter, the main conclusions following from the study are summarised, and the consequences for Forbo-Krommenie B.V. are outlined.

7.1 Main conclusions from inventory, impact assessment and interpretation summarised

Data gaps

No process data was available for the following processes:

- The production and transport of pesticides (use and emission of pesticides is included).
- The production and transport of the fertiliser S needed in the process “growing linseed “ .
- The production and transport of some raw materials needed for maintenance products (additives, thickeners, solvents) and almost all ingredients for those materials.
- The production and transport of some raw materials needed for the production of materials used during laying (adhesives and materials used to seal the seams for professionally used linoleum floors).
- The production and transport of a catalyst needed in the process “esterification of tall oil “.
- The production and transport of the maintenance product used for removing the polymer dressing on linoleum floor covering needed in the process “the use and maintenance of 1m2 linoleum for 20 years “.

Flows not assigned to an impact category

In total there are 264 inputs/outputs that could not be assigned to an impact category. These are mainly from the ETH database. A large portion of the emissions (132 emissions) are radioactive emissions. Since radiation is not included in this study (because no consensus has yet been reached concerning the impact assessment method to be used) it could not be included in the impact assessment results.

Main contributing processes

The processes or groups of processes that contribute largely to more than one impact category are:

- The growing of linseed (emissions of NH_3, N_20 , pesticides).
- Gas and electricity used at Forbo-Krommenie B.V.
- Oil used for the production of maintenance products.
- The transport of raw materials.
- The incineration of linoleum.
- Coal used for the production of detergents and acrylic dispersions/emulsions.

Scenarios

The following conclusions were drawn from the scenarios:

- Extra transport by freighter to the USA has less impact than was expected.
- The influence of maintenance in the “use “ phase is not negligible as is often thought.
- The influence of other pigments than TiO2 can be considerable. TiO2 is not representative for other pigments. The impact of other pigments may be high even though their mass share in the product is much lower.
- Using tall oil in linoleum is better for the environment than using only linseed oil.
- Using 2.0 mm linoleum is better for the environment. However, this is only the case if the life span of the 2.0 mm linoleum is more or less the same as for the 2.5 mm version.
- Substitution of useful heat produced during the incinerating of linoleum with avoided electricity use is the best of the studied alternatives.
- Reduction in the use of pesticide only effects terrestrial ecotoxicity, and not the other toxicity categories.
- Reduction in the use of N-fertiliser affects the results for global warming, eutrophication and acidification substantially.

- Reduction of the transportation distance for raw materials has some effect on aquatic and sediment ecotoxicity.
- Changes in the composition of the VOC emissions at Forbo-Krommenie B.V. have a considerable influence on the category “odour “. A better estimate of the composition of these emissions is necessary in order to assess the effects on “odour “ and “depletion of the ozone layer “ properly in an LCA on linoleum products.
- The influence of capital goods is certainly not negligible. According to a very rough scenario leaving out capital goods may lead to an underestimation of 1-10%. The influence of the missing chemicals could be even more substantial. According to a very rough scenario these data gaps may lead to an underestimation of 5-40%.

7.2 Discussion & final conclusions

Main contributing processes

In the stage “production of raw materials “ the growing of linseed and transport are important processes. The growing of linseed is overall a very important process contributing greatly to more than 5 impact categories (see § 6.1.3), mainly caused by the emissions of NH_3. The data for this process is valid because it is representative. However, its reliability may be disputed. The emissions of both NH_3, N_2O and pesticides depend largely on assumptions. If these assumptions are not realistic, this may have large influences on results (see the scenarios in 6.4.4). Therefore it is advisable to try to ground these assumptions with better data. Still, Forbo-Krommenie B.V. could improve their environmental performance on many impact categories by using linseed that is cultivated with less fertiliser and less pesticides.

This high impact of the process “growing of linseed” also is responsible for the difference between linoleum with and without tall oil (see scenario in 6.4.2). Linoleum with tall oil has a better environmental profile than linoleum without tall oil because the use of linseed is lower. Therefore, reduction of the amount of tall oil in favour of linseed oil does not improve environmental performance.

In the stage “production of linoleum “ the energy used at Forbo-Krommenie B.V. is most important. We expect that this data is valid and reliable. Saving on the use of electricity and gas is therefore an opportunity for improvement. This is an option or which Forbo-Krommenie B.V. is not dependent on its suppliers.

In the stage “laying and use “, the coal and oil used during the production of maintenance products is important. Data on the production of maintenance products is not complete. Therefore, in the scenario analysis, maintenance options were analysed in greater detail (see § 6.4.1) The results of the comparison of the Dutch and Swedish scenario showed a heavy influence of the lack of data on the production of Swedish maintenance products (see scenarios in § 6.4.1). Therefore, no conclusions can be based on the comparison of these maintenance systems, other than that maintenance is not negligible. Better data on maintenance products is needed before more conclusions can be drawn on the influence of maintenance.

In the stage “disposal “ the emissions produced during incineration are important. However the figure of 100% incineration of used linoleum and the linoleum waste from Forbo-Krommenie B.V., is only an assumption. Therefore, a sensitivity analysis has been carried out in which the waste is not incinerated but landfilled (see 6.4.3). From this scenario followed that substitution of useful heat produced during the incinerating of linoleum with avoided electricity use shows the best environmental profile of the studied alternatives. Therefore incineration seems a better alternative than landfilling. However, this result should be considered with some care, because for landfilling average ETH-data was used. These are probably not very realistic for the landfill of linoleum.

Composition of linoleum

In the scenarios a number of variation in linoleum composition have been studied (see § 6.4.2). This showed that:

- The pigments used can have a large influence on environmental performance. However the data on pigments could not be checked for quality. Moreover, these data were not provided by the suppliers of the pigments and the representativeness of these data might be disputed. A more detailed analysis on this point focusing on the pigments which are actually used by Forbo-Krommenie B.V., aimed at finding pigments which are the most environment-friendly could be valuable**.**
- The 2.0 mm gauge has a considerably better environmental performance than the 2.5 mm gauge. On average, the results for this gauge are 15% lower. If the life span of both floors is comparable, Forbo-Krommenie B.V. might consider producing relatively more 2.0 mm products and advising their use on well-smoothed surfaces as a means of improving their environmental performance.
- Linoleum with tall oil has a better environmental profile than linoleum without tall oil because the use of linseed is lower (see also discussing before on linseed).
- Compared to the baseline 2.5 mm linoleum cork linoleum produces better results in most categories, but performs considerably worse in the categories “abiotic depletion “ and “odour “. Were the gas use during drying and milling of cork-granulate reduced, it would improve the results for these categories.

Datagaps

The influence of capital goods is certainly not negligible. According to a very rough scenario leaving out capital goods may lead to an underestimation of 1-10% (see § 6.5). The influence of the missing chemicals could be even more substantial. According to a very rough scenario these data gaps may lead to an underestimation of 5-40% (see § 6.5). Therefore, the results should not be used to compare systems with different capital goods or different maintenance systems. The results of the study are applicable for analysis of the described systems only.

VOC

The result for “odour “ and “depletion of the ozone layer “ should be considered with some care, since the emissions of VOC from Forbo-Krommenie B.V., which play an important role in these impact categories, were not specified. From the scenario in § 6.4.4 followed that the individual VOC composition of the emission from Frobo-Kromenie B.V. can have a large influence the results for “odour”.

7.3 Improvement options & advice for further studies

7.3.1 Options to improve environmental performance of Forbo-Krommenie B.V.

Raw material use

Forbo-Krommenie B.V. could improve their environmental performance on many impact categories by using linseed that is cultivated with less fertiliser and less pesticides. This seems a more promising option than reducing transportation distances for raw materials.

Energy use

Not surprisingly, saving on the use of electricity and gas is also an opportunity for improvement. This is an option or which Forbo-Krommenie B.V. is not dependent on its suppliers.

Composition of linoleum

The pigments used can have a large influence on environmental performance. A more detailed analysis on this point, aimed at finding pigments which are the most environment-friendly could be valuable**.**

The 2.0 mm gauge has a considerably better environmental performance than the 2.5 mm gauge. On average, the results for this gauge are 15% lower. If the life span of both floors is comparable, Forbo-Krommenie B.V. might consider producing relatively more 2.0 mm products and advising their use on well-smoothed surfaces as a means of improving their environmental performance.

Linoleum with tall oil has a better environmental profile than linoleum without tall oil because the use of linseed is lower. Therefore, reduction of the amount of tall oil in favour of linseed oil does not improve environmental performance.

Compared to the baseline 2.5 mm linoleum cork linoleum produces better results in most categories, but performs considerably worse in the categories “abiotic depletion “ and “odour “. Were the gas use during drying and milling of cork-granulate reduced, it would improve the results for these categories.

7.3.2 Advice for future studies on linoleum

We advice giving the following topics extra attention in future studies on linoleum, as the data on these topics is fragmented and their influence on the environmental profile of linoleum could be considerable:

- The production and use of maintenance products, especially the Swedish type
- The production and use of pigments other than TiO2. There is a great variety of possible pigments, but little information is available concerning their environmental performance. Our sensitivity analysis showed that the contribution of these pigments can be considerable.
- Emissions of individual VOC at the site of Forbo-Krommenie B.V.

Given the normative nature of evaluation and weighting, this step should be separated from the characterisation step (conform ISO), for transparency reasons and to show the effects of various assumptions. Therefore, we advise using a two step method for future LCA-studies on linoleum products. As no independent nationally or internationally authorised weighting sets are currently available, we advise using no weighting, if this not necessary.

8 References

Ahbe, S., A. Braunschweig, & R. Müller-Wenk, 1990: *Methodik für Oekobilanzen, auf der Basis ökologischer Optimierung*. Schriftenreihe Umwelt Nr 133, Bundesamt für Umwelt, Wald und Landshaft (BUWAL), Bern, Switzerland

Baumann, H., 1992: *LCA: Utvärdering med index. Beräkning av tva uppsättningar norska index.* CIT-ekologik 1992:2. Chalmers, Göteborg. Sweden.

Berg, N, W. van den, G. Huppes, E.W. Lindeijer, B.L. van der Ven & M.N. Wrisberg, 1998: *Quality assessment in LCA. Framework and survey, draft.*

Blonk, T.J., M. Lafleur, R. Spriensma, S. Stevens, M. Goedkoop, A. Agterberg, B. van Engelenburg & K. Blok, 1997: *Drie referentieniveaus voor normalisatie in LCA: Nederlands grondgebied 1993/1994; Nederlandse eindconsumptie 1993/1994; West-Europees grondgebied begin jaren 1990.* RIZA-werkdocument 97.110x.

Braunschweig, A., R. Förster, P. Hofstetter, R. Müller-Wenk, 1994: *Evaluation und Weiterentwicklung von Bewertungsmethoden für Ökobilanzen - Erste Ergebnisse*. IWÖ-Diskussionsbeitrag Nr 19, Zwischenbericht des Nationalprojects Nr 5001-35066, SSP Umwelt, Institut für Wirtschaft und Ökologie (IWÖ) St. Gallen, Switzerland

Davis, J & C. Haglund, 1999: *Life Cycle Inventory (LCI) of fertiliser production.* SIK-report No. 654. Chalmers University of Technology, Sweden.

Derwent, R.G., M.E. Jenkin, S.M. Saunders & M.J. Pilling, 1998: *Photochemical ozone creation potentials for organic compounds in Northwest Europe calculated with a master chemical mechanism.* Atmospheric Environment, 32. p 2429-2441.

EC (European Commission), 1995: *ExternE: Externalities of Energy.* Volume 1-5. European Commission, Directorate-General XII, Science, Research and Development, Luxembourg

ETH, 1996: *Ökoinventare von Energiesystemen.* Eidgenössische Technische Hochschule, Zürich. Database.

Goedkoop, M., 1995: *The Ecoindicator 95, Weighting method for environmental effects that damage ecosystems or human health on a European scale*. Final report, NOH report 9523, Pre Consultants, Amersfoort, Netherlands.

Guinée, J.B., 1995. *Development of a methodology for the environmental life-cycle assessment of products; with a case study on margarines.* Thesis, Leiden University.

Guinée, J.B., M. Gorree, R. Heijungs, G. Huppes, R. Kleijn, H.A. Udo de Haes, E. van der Voet & M.N. Wrisberg, 2000: *Environmental Life Cycle Assessment. Backgrounds.* Centre of Environmental Science (CML), Leiden University, Leiden. In prep. draft version October 1998 available on the website: http://www.leidenuniv.nl/interfac/cml/lca2/index.html

Günther, A. & H.C. Langowski, 1997: *Life Cycle Assessment study on resilient floor coverings.* Int. J. LCA 2 (2). pp. 73-80.

Hauschild, M & H. Wenzel, 1998: *Environmental Assessment of products. Volume 2: Scientific background*. Chapman & Hall, London.

Heijungs, R. 2000. CMLCA 2.0. on website: http://www.leidenuniv.nl/interfac/cml/ssp/cmlca.html.

Heijungs, R., J.B. Guinée, G. Huppes, R.M. Lankreijer, H.A. Udo de Haes, A. Wegener Sleeswijk, A.M.M. Ansems, P.G. Eggels, R. van Duin & H.P. de Goede, 1992: *Environmental Life Cycle Assessment of products. Guide and Backgrounds.* Centre of Environmental Science (CML), Leiden University, Leiden.

Houghton, J.T., L.G. Meira Filho, J. Bruce, H. Lee, B.A. Callander, E. Haites, N. Harris & K. Maskell (eds), 1994: *Climate change 1994. Radiative forcing of climate change and an evaluation of the IPCC IS92 Emissions scenarios*. Cambridge University Press, Cambridge.

Houghton, J.T., L.G. Meira Filho, B.A. Callander, N. Harris, A. Kattenberg & K. Maskell, 1995: *Climate change 1995. The science of climate change; contribution of WGI to the second assessment report of the intergovernmental panel on climate change.* Cambridge University Press, Cambridge.

Huijbregts, M.A.J., 1999a: *Priority assessment of toxic substances in LCA. Development and application of the multi-media fate, exposure and effect model USES-LCA.* Interfaculty Department of Environmental Science, Faculty of Environmental Science, University of Amsterdam, Amsterdam.

Huijbregts, M.A.J., 1999b: *Life-cycle impact assessment of acidifying and eutrophying air pollutants. I: Calculation of equivalency factors with RAINS-LCA.* Interfaculty Department of Environmental Science, Faculty of Environmental Science, University of Amsterdam, Amsterdam.

ILV, 1991: *Umweltprofile von Packstoffen und Packmitteln, Methode (Entwurf).* Fraunhofer-Institut für Lebensmitteltechnologie und Verpackung, Gesellschaft für Verpackungsmarktforschung, Institut für Energy- und Umweltforschung, München.

ISO 14040, 1997: ISO 14040: 1997, *Environmental management – Life cycle assessment – Principles and framework.* International Organisation for Standardisation (ISO).

ISO 14041, 1998: Final draft ISO/FDIS 14041. *Environmental management – Life cycle assessment – Goal and scope definition and inventory analysis.* International Organisation for Standardisation (ISO).

ISO 14042, 1999: Final draft ISO/FDIS 14042*. Environmental management - Life cycle assessment - Life cycle impact assessment.* International Organisation for Standardisation (ISO).

ISO 14043, 1998: Committee draft ISO/DIS 14043. *Environmental management - Life cycle assessment - Life cycle interpretation*. International Organisation for Standardisation (ISO).

Jöhnsson, A., A.M. Tillman & T. Svensson, 1995: *Life-cycle assessment of flooring materials.* Report A5: 1995. Swedish Council for building research.

Jenkin, M.E. & G.D. Hayman, 1999. *Photochemical ozone creation potentials for oxygenated volatile organic compounds: sensitivity to variations in kinetic and mechanistic parameters.* Atmospheric Environment, 33. p 1275-21293.

Loo, S van & de Koning, J, 1994: *Oriëntatie op de thermische verwerking van Marmoleum* (In Dutch). TNO, MEP, Apeldoorn, The Netherlands.

PE, 1999: Product Engeneering, Dettingen, Germany: Personal communications Dr. K. Saur.

Potting, J & K. Blok, 1993: *The environmental life-cycle assessment of four types of floor covering.* Science shop co-ordinating centre of Utrecht University, Utrecht.

Steen, B. & S.O.Ryding, 1993: *The EPS Enviro-Accounting Method, An Application of Environmental Accounting Principles for Evaluation and Valuation of Environmental Impact in Product Design*. AFR-report 11, Avfallsforskningsradet (AFR), Swedish Environmental Protection Agency, Stockholm, Sweden

Steen, B., 1996: *EPS-Default Valuation of Environmental Impacts from Emission and Use of Resources*. Version 1996, AFR report 111, Avfallsforskningsradet (AFR), Swedish Environmental Protection Agency, Stockholm, Sweden

Välimaa, C. & M. Stadig, 1998: *Växtnäring I livscykelanalys.* Swedish Institute for food and biotechnology. SIK-rapport nr. 637 1998.

WMO (world Meteorological Organisation), 1992: S*cientific assessment of ozone depletion: 1991*. Report no. 25. Geneva.

WMO (world Meteorological Organisation), 1995: *Scientific assessment of ozone depletion: 1994*. Report no. 37. Geneva.

WMO (world Meteorological Organisation), 1998: *Scientific assessment of ozone depletion: 1998*. Report no. 44. Geneva.

Wrisberg, M.N. N.W. an den Berg, G. Huppes, E. Lindeijer & B.L. van der Ven, 1999: *Operational quality assessment in LCA: A semi quantitative method, draft.*

Appendices