Recycling aspects in Life Cycle Assessments, exemplified by calculations on insulation materials

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Abstract

Lifecycle assessment is a tool to identify and evaluate the environmental impact of a product system, which can be used in the general strive towards a more sustainable society. The building sector is a major contributor to the environmental loads generated by society. Lifecycle assessment can be useful here, to help enhancing the environmental performance of the sector.

The EcoEffect model is a computerised tool that uses the LCA methodology to assess the environmental impacts of material and energy flows through a property or building system. The aim of decreasing the environmental impacts caused by these flows in the building sector, puts the recycling aspect very much in focus. In the EcoEffect model this aspect is still not included but the ambition is to do so, using this work as a feasibility study in the area.

Methods of distributing environmental loads in recycling systems have been evaluated and suggested for reusable-product systems and energy recovery systems. A variant of the 50/50-method was applied on the reusable-product system and the method of expanding system boundaries on energy recovery systems.

The methods were tested on five different insulation materials with varying recycling capacities. Due to lack of data, calculations for the different product systems does only regard energy requirements and emissions to air. Results does consequently not give the entire picture for how the product systems affect the environment and different insulation products could therefore not be compared with respect to their environmental soundness.

Acknowledgement

By bringing this work to an end I hope to conclude my education in environmental sciences, which has been performed at the University of Umeå during the last five years.
The final degree thesis last one semester and is an obligatory element for all educations in civil engineering.
This work has been performed at the Royal Institute of Technology and at the division for urban studies. It has been part of a research programme called EcoEffect which is supervised by Mauritz Glaumann, senior lecturer at the University of Gävle.

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Content

1. INTRODUCTION

1.1 THE BUILDING SECTOR AND THE ENVIRONMENT

In the Bruntdland report 1987, sustainable development was defined as a "development that meets the needs of the present without compromising the ability of future generations to meet their own needs". Based on this report and other documents like the Rio declaration 1992 and the Kyoto protocol 1997, the 15 environmental quality objectives was set up by the Swedish parliament in1999, to minimise the society´s impact on the environment.
The building sector is very much affected by these goals, since this industry strongly influences the environment. In the European Union, buildings are responsible for more than 40% of the total energy use and the construction sector is estimated to generate approximately 40% of all man-made wastes (Paulsen 2001). Sector specific goals for material and energy flows and for the indoor environment are to be fulfilled by the building sector, to reduce the environmental impacts and to meat the overarching goal "a good built environment" (Boverket, 1999)
In order to identify and improve the environmental performance of the building sector, access to tools for environmental assessment is a precondition (Trinius, 1999). Life cycle assessment (LCA) is such an assessment tool initially used in the 1960´s for industrial production systems, but that now is being applied also in the building sector.

A buildings lifecycle does generally include: extraction and production of raw materials; production of building materials or components; construction/installation; use and maintenance of a function, provided by building product; dismantling; waste treatment, disposal or recycling/reuse. These different stages have been illustrated in figure 1.1
The Eco-Effect method suggests a procedure to adapt the LCA methodology to the building sector which is further discussed in chapter 1.2.

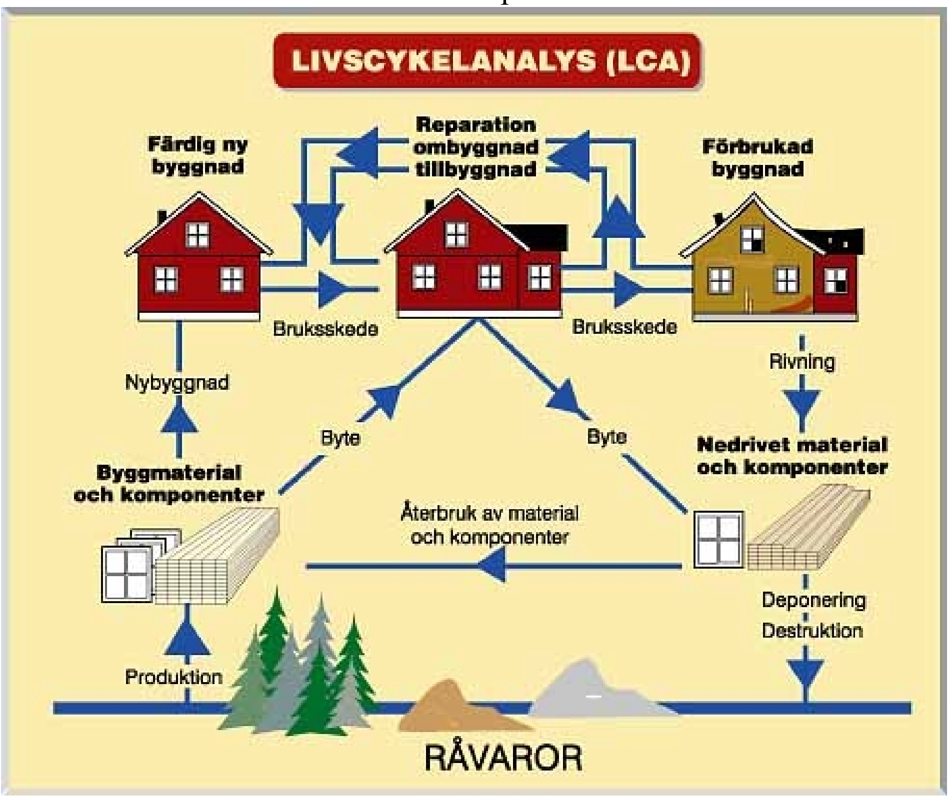

Figure 1.1 Included elements in the lifecycle of a building. The illustration is available at http://www.sp.se.

1.2 THE ECO-EFFECT METHOD

The EcoEffect-method is a method that calculates and assesses environmental impacts caused by the usage of a property, building and site, during an assumed lifetime (Glaumann 1999). The EcoEffect method has been prepared since 1997-98 and is still under development. The goal is to find a methodology that can be used to quantitatively assess local and global impacts on the environment, as objectively as possible.
For energy and material flows the method generally follows the "cradle to grave" approach, which necessitates identification of the products life cycle and of the processes participating in it. "Products" refers both to materials, products and services related to the property.
The indoor environment and the outdoor environment of the property are also assessed in the EcoEffect method, but then using another more qualitative approach.

This report concentrates on recycling aspects in the building material flow, for which the method applies the LCA methodology. The material flow is here assessed with respect to the exterior environment only. Possible indoor effects caused by the materials will consequently not be revealed in this part of the assessment. The overall indoor environment is included in the model, using a criteria based assessment. This evaluation is not further commented in this report.
Since the goal of EcoEffect is to improve the environmental performance of a building/property, the recycling aspect is of great importance and should be included in the model.

The EcoEffect-model has recognised two different aims regarding recycling:
1. Use of recycled material in the construction phase
2. To prepare for and simplify future recycling (reuse, material recycling, incineration with heat recovery etc.)

There are two main benefits normally associated with recycling eg. resource saving and energy saving. Both these conditions must be satisfied to justify recycling
There are, however, several options of calculating the environmental load for recycled products, which subsequently influences the picture.
The probably most important and hardest task is to distribute the estimated environmental load over the assessed material and its recycled variant.
It is very difficult to find a general and a fair method of distributing the environmental loads associated with materials and components that are recycled into new variants. In LCA terminology this kind of difficulties are called *allocation problems*, which are further discussed in chapter 2.5.

1.3 GOAL OF THE RESEARCH

The goal of this Master of Science Thesis work can be divided into three separate parts;

1.) Describing existing methods of distributing environmental loads over a product and its recycled variant.
2.) Defining a suitable allocation procedure for recycled products, which follows the goals and aims of the EcoEffect model.
3.) To test the model by assessing environmental impacts of different insulation materials with varying recycling potentials, according to the defined allocation procedure.

1.4 MATERIAL AND METHOD

The original goal of the study was to calculate environmental loads for as many recycled variants of building materials as possible and to test the results in the EcoEffect model. Interviews and visits where made with contractors at demolition sites and with environmental technicians at recycling plants. Roland Nilsson at RIVNERS and Magdalena Westerberg at SRV-recycling, are names that can be used as references.

It was however not possible to start calculating environmental loads without knowing how to distribute the environmental loads over the original building material and its recycled variant. This insight lead to a theoretic investigation on allocation procedures for recycling scenarios, for which several doctoral studies and other scientific research work were used. Some of the procedures was discussed directly with professionals, such as Göran Finnveden from the environmental strategies research Group, Stockholm and Mauritz Glaumann, KTH.

Seminars focusing on the allocation problem in general and in recycling specific cases, was attended to enhance the understanding of load distributions.

This work is consequently focusing on the methodology of distributing environmental loads, with the goal of finding a general allocation method for recycled products in the EcoEffect model.

To test the method, five insulation materials with different recycling potential were selected and assessed with the EcoEffect model. Environmental data were received from each manufacturer, from contractors and from scientific reports.

The general lifecycle assessment procedure, described by the ISO 14040-14043, was followed and the assessment steps performed with the EcoEffect model.

2. LIFE CYCLE ASSESSMENT

Life Cycle Assessment is a technique for assessing the environmental aspects and potential impacts associated with a product by (ISO 14040)(ISO 14041) and (ISO 14042)

1.) Compiling an inventory of relevant inputs and outputs of a product system
2.) Evaluating the potential environmental impacts associated with those inputs and outputs
3.) Interpreting the results of the inventory analysis and impact assessment phases in relation to the objectives of the study

The impacts on resource use, human health and ecological consequences are generally considered and associated with the input and output flows of the analysed system.
The different phases of LCA are described below, mainly based on the ISO-standard.

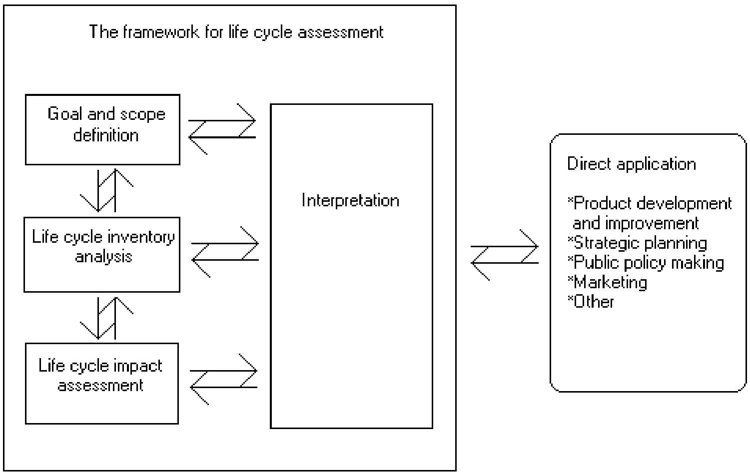

Figure 2.1 Phases of an LCA (ISO, 1997).

2.1 GOAL AND SCOPE DEFINITION

The first step of a lifecycle assessment is to define the goal of the study. The definition should clearly state the purpose of the study and the intended use and users of the results (Lindfors et al., 1995).
In the scope of the study is where we identify and define the object of the study. It shall contain information of what has been included and excluded in the study and the level of detail of the data. Items that are considered crucial for the extent and content of the scope are; the functional unit; the system to be studied; the system boundaries; allocation procedures; the types of impacts and the methodology of impact assessment and subsequent interpretation to be used; data requirement; limitations, the type of critical review.

2.2 INVENTORY ANALYSIS

This phase consists of two main parts: data collection and calculation procedures.
Data for the unit processes is collected according to the scope definition, which states the borders of the system under study. The information is then related to the functional unit through calculation procedures and presented in tables or histograms.

Life cycle inventory analysis (LCI) are analysis that terminate at this point and omit the two final phases of an LCA that deals with impact assessment and result interpretation. In an LCA these results are however only sub-results that must be analysed further.

2.3 IMPACT ASSESSMENT

This is the phase where a probable estimation is made of the impacts on the environment caused by the system under study.
Impact categories are chosen and defined in the first part of this phase. In the second and third part of the impact assessment the LCI results from the inventory analysis are classified and characterized with respect to the impact categories.
The categories shall be selected so that they are in compliance with the goal and scope of the study.
The impact categories regarded in the Eco-effect model for material and energy flows are (Glaumann, 1999):

- *Emissions*: Global warming; Acidification; Eutrophication; Stratospheric ozone depletion; Photo-oxidant formation; Human toxicological effects; Eco-toxicological effects.
- *Waste*: Non-toxic waste; Radioactive waste; slag and ashes; Toxic waste
- *Natural resource depletion*: (fuels, metals, etc.)

When the emissions, wastes and resources of the system under study are classified, they become assigned to the different impact categories. During a characterisation step, each load within a category is given a specific effect factor. This factor is calculated with respect to the relative importance of a load for a specific category.
As an optional element in the life cycle impact assessment a final weighting step can be performed. This is based on numerical hierarchy where each category is ranked according to its relative importance, to give a final and single value for the total environmental load.

Unfortunately, despite the fact that lifecycle analysis is defined as an objective method of describing a products environmental impact from cradle to grave (Borg 1996), the assumptions made by the investigator is most probably decisive to the outcome of the study.

2.4 RESULT INTERPRETATION

In this, last phase of an LCA, the results are discussed and significant issues are identified. The results should also be evaluated with respect to their completeness, accuracy and consistency to give a better understanding of their characteristics.
The result interpretation also deals with the drawing of conclusions, recommendations and reporting. It is important that the results have been presented with full transparency in order to prevent misinterpretations, so that these elements can be used for the right purposes.

2.5 ALLOCATION OF ENVIRONMENTAL LOADS

When several product systems share a common process it may result in a so-called allocation problem. This problem arises when the environmental impacts are to be distributed “fairly” between different products.
Often three different situations are distinguished (Finnveden, 1996):
1) Co-production (multi-output processes)
2) Waste treatment processes (multi-input processes)
3) When something is recycled into a secondary product.

There are many possibilities to perform an allocation for different situations, every process is unique and must be studied individually in order to receive the best result.

2.5.1 Principles for allocation in the case of recycling

In the case of recycling, the allocation deals with the distribution of the environmental loads from raw material based production, secondary material based production, recycling procedures, waste treatment and attributable transportation in-between the products participating in recycling activities (Borg, 2001)
Allocation in the case of recycling is usually divided into two types: Closed-loop and Open-loop allocation.

2.5.2 Closed-loop recycling

When a product or a material is recycled into the same function each time it is defined as a Closed-loop recycling system. The allocation problem occurring for this system is defined as Closed-loop allocation (Borg, 2001)
Reusing a building material or a building component is one example of closed-loop recycling. Eco-fibre and Termoträ are two examples of insulation materials that can be reused. These cellulose fibres can be exhausted from a construction with a suction tube and thereafter be blown into another construction. These two materials are assessed later in this report, with respect to an allocation procedure described in chapter 4.

2.5.3 Open-loop recycling

Recycling systems that do not produce the same product each time, are defined as Open-loop recycling systems. The open-loop allocation problem consists of three parts, where environmental loads of the system are to be allocated between the product and its recycled variant (Lindfors et al., 1995), which occurs when

* Production of primary material used in both products
* The recycling system
* Disposal of materials used in both products

Many different methods for handling the open-loop allocation problem have been presented and tested in case studies, but no procedure seems to prove that any of these methods is indisputable (Finnveden et al. 2000)
The most commonly used methods are presented bellow:

EPS-method: This is an evaluation method that takes the quality reduction between life cycles into account when dealing with the allocation problem (Borg, 1997)
Cut-off-method: This method is based on the opinion that each product should only be assigned the environmental loads caused by production of the product, and thus allowing the following cycles to be disregarded (Borg, 2001)
50/50-method: The first and the last product in the assessed lifecycle will share the environmental impact price that arises during virginal production and waste management. Environmental impacts from recycling processes are shared 50% for the studied lifecycle and 50% on the previous life cycle (Borg, 1997).
Östermark-method: The environmental impact from virgin production and waste treatment is allocated with respect to the proportion of virgin material in the product. The environmental impact from recycling processes is allocated with respect to the amount of recycled material in the product (Borg, 1997).

Other methods like the Economy- or IPU-method distributes the environmental impact price for virginal production, waste management or recycling in proportion to the market value of the products.

2.5.4 Avoiding the Open-loop allocation problem by expanding the system boundaries

Another way to deal with the Open-loop allocation problem is simply to avoid it by expanding the system boundaries and include several functions within the system. Broadening the system also provides a more complete and therefore a more accurate model of the system (Finnveden 1996)

In the expanded system the recycling method is compared with an alternative method of producing the same product. One way of using the expanded system is to subtract the alternative producing system from the recycling system (Finnveden et al., 2000).

Systems presented in this way may result in negative environmental interventions if the alternative producing system has a larger impact on the environment than the recycling system (Finnveden et. al 2000).

The use of expanded system is quite easy as long as the alternative product can be determined, but in many cases the model becomes large and complicated (Finnveden, 1996).

System expansion is recommended by the ISO-standard (ISO 1998) and in the Nordic Guidelines (Finnveden et al. 2000)

When using system expansion there are some critical questions to consider (Finnveden et al. 2000).

1) What material will the recycled material replace? Virgin material of the same kind, virgin material of another kind or other recycled materials.
2) Are the demands independent of how the products are produced? It is generally assumed that there is no connection between the demand of a product and how it is produced. The system model is thus a simplification of the real system.
3) Are the functional qualities of the products and/or material similar and independent of how they are produced? It is often assumed that the recycled material can replace another material having similar functional qualities.

One example of an open-loop system is when waste is incinerated with energy recovery. The energy that is produced can be regarded as the recycled variant of the material that is burned. EPS (Expanded polystyrene) is an insulation material produced from petrochemical products with large calorific values. When this material is incinerated a great amount of energy is produced and can be regarded its recycled variant.

EPS is consequently part of a two function product system, where the first function is to insulate and the second to generate heat.

In this study, EPS is assessed according to the expanded system boundary methodology.

3. RECYCLING ASPECTS IN THE BUILDING SECTOR

3.1 THE GENERAL TREATMENT HIERARCHY

During recent years the building sector has been forced to regard new alternatives for treating its generated waste. Depositing costs become more and more expensive as politicians keep using the tax system as a tool to reach environmental goals.

Alternative options for managing construction waste must be evaluated and their consequences assessed in order to make strategic decisions on this matter.

In a study made by G. Finnveden, 2000, a general treatment hierarchy for solid waste was tested and suggested:

1. Reduce the amount of waste
2. Reuse
3. Material recycling
4. Incinerate with heat recovery
5. Landfill

This hierarchy is more or less applicable for all kinds of waste but is dependent on the available technology, infrastructure, etc. in each case.

The first priority, to reduce the amount of waste leads us to question our modern lifestyle, which is generally based on a "use and throw" philosophy.
In the building sector, materials and components are often replaced, even if they still serve their function. Renovations are in some cases performed due to aesthetic demands, an action that is not easily defended, relative to the concept of a sustainable development.

Reuse can ,however, decrease the impacts of our bad behaviour by replacing products produced from virgin materials. Reuse means that a product is used again for the same purpose.
Quality reduction is a very important aspect that must be regarded in this type of treatment. The majority of products used in the building sector are produced according to Swedish Standards (SS), a quality insurance that some reused products do not have. Boverket has suggested some methods of evaluating the quality of reused products, such as timber and bricks (Boverket, 1997), but there is still a general scepticism among the building contractors for reused products(Nilsson. R, 2001)

Recycling is a generally used concept for taking care of old products in order to use them again in the same or another form. Recycling often includes some kind of process where raw material is extracted from the old product and used in a new production process. Recycling of metals is a typical example of material recovery. These procedures generally imply a better control of the quality than in the previous case that dealt with reuse. A more important aspect in this case is the recyclability of the materials and components, included in the building.
If the construction is too complex and if it is difficult to separate materials from one another, then the dismantling process will take longer time and the material fractions will most likely be contaminated, which results in a lower recycling potential.
Contaminated fractions might imply a cleaning step, which in some cases implies an addition of chemical substances and energy. This is an environmental aspect that must be regarded when assessing the impact of recycling.
Incineration with heat recovery is in many cases regarded as less favourable since it does contribute to global warming by CO_2 emissions to air. It is however in general, favourable over landfill (Finnveden et al. 2000) when it replaces other energy carriers such as fossil fuels, which are non-renewable.

Landfill is generally regarded as the least considerable option and will be prohibited in Sweden for any combustible waste by 2005 (Swedish Parliament, 1996). The new tax system for waste products aims at lowering the amount of waste being put on landfill by making it economically unviable.

The Ecocycle Council for the Building Sector, has stated the following overarching goals to limit the environmental impacts caused by the production of building materials (EPS producenterna, 1995);

1) Limit the usage of hazardous products and materials during the construction phase, during the usage period of the building and in the production of packaging materials for building products.
2) Reuse and recycle as big volumes of waste products from the building sector as possible.
3) See to that the remaining fraction of waste that cannot be reused or recycled is treated in an environmentally acceptable way.
4) To develop environmentally sound building products

To reach these goals, the building sector must be tackle the waste problem from all sides and especially focus on the recycling aspect.
Existing systems for recycling can be optimised and in the case of reuse, methods of quality determination have to be developed and better defined.
One example of optimising recycling systems is to decrease the transportation distances that are related to the recycling activities. In many cases, too long distances can be used as a good excuse for not recycling.
Another, more preventive approach, is to successively replace "bad" building products with "good", environmentally sound products.

In a report about ecological building made by The National Board of Housing, Building and Planing in 1998, the environmental soundness has been evaluated for three different ambition levels. Building according to basic standards is suggested as the lowest ambition. The next ambition level is to use materials and components that have been classified as good environmental choices. The last level is referred to as ecological building and requires a big portion of personal involvement. This is the only level that is considered conform to a sustainable development and does thus show us how much we have to work in order to reach this overarching goal.

3.2 CURRENT TREATMENT STATISTICS FOR BUILDING WASTE

Several studies with the goal of surveying the recycling potential for building waste has been performed commissioned by the government and private companies, during recent years.
In 1996, the *Environmental Protection Agency* surveyed the material flows in the construction sector and suggested an actual picture for the destiny of construction waste. Part of the result from this survey is presented here to give an overview of the different materials used in the building sector, and to show how they are treated after being dismantled.
The treatment methods do however differ from region to region and are dependent on accessibility to incineration plants, recycling plants etc. Plastics are for example incinerated up to 75% in Stockholm and Malmö but the mean value for all regions is 20-25 %.
The data presented is an average of estimations made by consultants, contractors and road carriers.

Material	Reuse (%)	Material recycling (%)	Combustion/ Incineration (%)	Landfill (%)
Concrete		20		80
Gypsum wallboard	<2	<5		90-95
Mineral wool		<1-2		98-99
Plastic			20-25	75-80
Mastics			20	80
Glass	35	<1		65
Wood			70-80/ 5-10	15-20
Metals		50-80		20-50
Bricks	<5	10-20		75-80
Building stone	90			10
Sand/Stone	90			10
Light weight concrete		10		90
Roof paper			20	80
Linolium			15	85
Paint[1]			20	60
Textile			15	85

Table 3.1 Proportion of building rubble that is reused, material recycled, incinerated and put on landfill.

Obviously the building sector causes a great amount of waste every year that is put directly on landfill or incinerated as waste material. According to the study by the Environmental Protection Agency, the materials with the least recycling potentials and most probability of being put on landfill are mineral wool and gypsum board.
Mineral wool is an insulation material that comprises both glass wool and stone wool. Both materials are widely used in Sweden and thus contributing to a growing waste mountain. There are however other insulation materials on the market that offer higher recycling potential. Are these materials better for the environment? Should we replace mineral wool with these insulation materials?

3.3 RECYCLING POTENTIAL OF DIFFERENT INSULATION MATERIAL

There are in general five different insulation materials on the market today (www.trahus.nu), which can be divided into three major groups:

1. *Mineral wool*: Glass wool and Stone wool
2. *Cellulose fibre*: Eco-fibre and Termoträ
3. *Plastic cell insulation*: Expanded polystyrene (EPS)

Every material has one or several product variants for different usage areas. Mineral wool material can be found with a variety of densities and cellulose fibres contain more or less fire retardant depending on where it shall be applied.
This study regards product variants that are generally used in wall constructions and that are certified by the Swedish testing and research institute (SP).

[1] The missing 20% has different destinies depending on the material it is attached to. Together with wood it might become object for combustion and together with concrete recycled in road constructions etc.

Each material group have been presented bellow, with focus on their recycling potential.

3.3.1 Mineral wool: Glass wool is produced from the basic components of glass, which are sand and lime. An increasing proportion of these virgin raw materials is however replaced by recycled bottles (Thormark, 1998). Glass wool manufactured by Isover Gullfiber, consists of 95% glass where 70% of those are recycled bottles from Swedish homes (Isover, 2001). Stone wool consists principally of silicon oxide together with a number of metallic oxides, and is created from abundantly available, volcanic diabase rock to which limestone and coke are added.

Reuse
Many sources state that reuse can be carried out for both glass wool and stone wool by tearing slabs into loose wool (Thormark, 1988)(Isover, 2001), which is true for clean pieces that have been left over from construction.
Mineral wool that has once been used for insulation purpose is however not considered clean and can thus not be reused in this way (Partheen, 2001).
In this study, reuse has therefore not been regarded as a possible recycling option for these two materials.

Material recovery
Mineral fibres can be recovered from both glass wool and stone wool (Thormark, 1998)(Isover, 2001), through a melting process. It is, however only viable for clean material, and is therefore not an option for used fibres.

Incineration with energy recovery
Neither of the two materials are combustible and can thus not be burned to give energy.

The only considerable option for mineral wool material waste is consequently landfill. Both glass wool and stone wool can be deposited without restrictions (Isover, 2001)

3.3.2 Cellulose fibre; The raw material for cellulose fibre is either wood or the paper from old daily newspaper (Thormark,1998).
The product commercialised as Termoträ consists of wood pulp that has been treated with ammonium polyphosphate to make it fire proved.
One of the other products assessed in this study is manufactured by the Swedish company Ekofiber and consists basically of recycled and granulated newspapers certified by Svanen (Ekofiber,1998). Boron compounds are added to the fibres to make it fire proved and as a barrier against micro organisms, (Thormark,1998).

Reuse
The product can be directly reused by exhausting the insulation fibres with a suction tube and than be reinstalled in another construction work. It is also possible to preserve and store the fibres in sacks until they can be reused.
In theory, this is the best option for taking care of old cellulose fibre, but there is still very little information available on how it has been practiced.
Research on quality reduction is going on at Svenska Termoträ AB and a recent test showed that the reused cellulose fibre might have even better insulating capacities than the original product (Sundin, 2001). More knowledge in this field is however needed.

Material recovery
Eco-fibre states that boron compounds and cellulose fibres in their product can be recycled separately as raw materials, or be recycled together as soil quality enhancer (Ekofiber, 1998). Also Termoträ states that their product can be recycled as a soil quality enhancer, but they do not agree to that the cellulose fibres and boron compounds can be recovered.
The material recovery option is still very theoretic and has not been practised in large scale. No more specific information is available for either of the two materials concerning material recovery and it has thus not been possible to assess this form of recycling for cellulose fibres.

Incineration with heat recovery
The cellulose fibre can be combusted, but information about combustion of materials with boron is not available (Thormark, 1998). The environmental impacts that this method involve is therefore difficult to determine.

Cellulose fibres can at present be put on landfill without restrictions (Termoträ, 1999)

3.3.3 Plastic cell insulation; Plastics are generally produced from the non renewable sources oil or gas. Four percent of the total global oil consumption is used for plastic production and 16% of those for plastic materials used in the building sector (Thormark, 1998)
The product called Expanded polystyrene (EPS) consists of very small polystyrene pearls that expand to closed cells filled with air (Plast- och kemibranscherna, 1997).
EPS manufactured for insulation purpose by the Swedish company Thermisol, consists to 98% of air and 2% polystyrene(www.termisol.se).

Reuse
No data or information have been found on reuse of EPS from building waste.

Material recovery
Clean EPS can be granulated and be part of new polystyrene products (Thermisol,2000). Dismantled EPS from buildings is however regarded as contaminated and can thus, not be recycled in his way(Gudmundsson, Thermisol 2001).

Incineration with energy recovery
One kg of EPS contains the same calorific value as 1,3 kg of crude oil (Plast och kemibranscherna, 1997) and does therefore contribute with a great amount of energy in waste incineration processes. This is very positive since higher temperature leads to lower and fewer emissions. When EPS is completely combusted, only water and carbon dioxide remain (Thermisol, 2000).

The options of treating the discussed insulation products have been summarised in table 3.2.

TREATMENT PRODUCT	Reuse	Material recycling	Incineration with energy recovery	Landfill
Glass wool				⊗
Stone wool				⊗
Eco-fibre	⊗	⊗	⊗	⊗[2]
Termoträ	⊗	⊗	⊗	⊗[2]
Plastic cell insulation (EPS)			⊗	⊗[2]

Table 3.2 A summary of treatment alternatives for insulation materials.

4. LIFE CYCLE ASSESSMENT OF FIVE INSULATION MATERIALS WITH DIFFERENT RECYCLING POTENTIAL

In this study five insulation materials have been divided into three groups with respect to their recycling potentials. These materials have thereafter been environmentally assessed, according to specific adaptations of the closed-loop and the open-loop methodologies discussed in chapters 2.5.2 and 2.5.3.

- Group 1 regards non-recyclable product systems and is represented by the mineral wool materials, Glass wool and Stone wool
- Group 2 deals with recycling as energy recovery systems and is represented by the plastic cell insulation, EPS.
- Group 3 regards reusable product systems and is represented by the cellulose fibres, Eco-fibre and Termoträ.

4.1 GOAL AND SCOPE DEFINITION

The main goal of this study is to answer the question that was asked earlier in this report: Does there exist better environmental alternatives on the insulation market than the mineral wool, according to defined allocation procedures and results from the EcoEffect model?

If the result is to be be representative, the difference in insulating capacity must be regarded. If 1 kg of each material is assessed the result will not show the overall impact change if one material is substituted with another.
The studied unit has therefor been chosen to be **the amount of each insulating material, that is required to insulate 1m^2 wall and give the heat resistance 6,67 m^2*C/W.**
Data received from www.trahus.nu does not take the the wall construction into consideration, only the thickness of each material, needed to give the specific value.

The weights of each studied material are presented in table 4.1.

[2] Putting combustible materials and products on landfill will be prohibited by the year 2005, Miljödepartementet, proposition 1996/97:172

Material	ρ (kg/m^3)	Thickness of insulation (m) needed to give 1/Up=6,67 m^2*C/W	Weight of the studied unit (kg)
Glass-wool	16	0,240	3,84
Stone-wool	28	0,240	6,72
Eco-fibre	52	0,260	13,52
Termoträ	48	0,260	12,48
EPS	15	0,240	3,60

Table 4.1 Weights for each material calculated with respect to the definition of the studied unit.

Other items to be included in the goal and scope definition are system boundaries and allocation procedures. These definitions have been presented for each material and group. The modelled building in which the assessed materials are assumedly used, is situated in the centre of Stockholm.

4.1.1 Non-recyclable product system

The earlier discussed waste hierarchy suggested that materials and components that become objects for landfill are the least favourable to the environment.
This system is, however, the easiest to assess since no secondary product is produced through recycling. These materials have only one function during their whole lifecycle, which in this case is to insulate a wall construction.

The materials considered in this group are Glass wool and Stone wool produced by Saint Gobain ISOVER AB.

Loads derived from the lifecycle of the product can fairly be allocated to the insulating product in question and have been defined in figure 4.1 as sub-loads: L1, t1, L2, t2, t3 and L3, where L = process loads and t = transport loads.

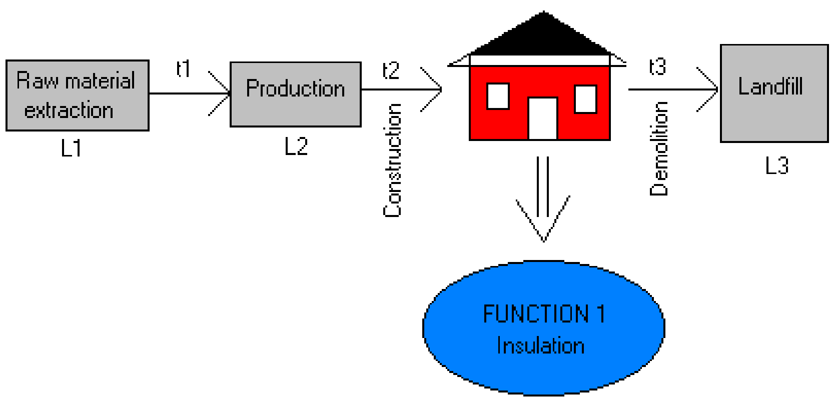

Figure 4.1 Considered loads for a non recyclable building product

Every box represents a number of activities related to a process that is part of the considered lifecycle. The sum of loads for the activities included in each box has been denominated L. Loads associated with transports between processes are denominated t.
Loads considered are: material and energy requirements; emissions to air and water; waste to land.

System boundaries:
Raw material extraction (L1)
Data for Glass wool and Stone wool received from ISOVER, Gullfiber regards energy requirements for extraction of minerals. Data for emissions to air and water, and amount of waste to land are not available at this moment.
Upstream loads associated with recycled bottles used in glass wool have not been allocated to the insulation product and they are consequently not regarded in this study. Loads associated with production of machinery and other equipment needed for the extraction process are not included, neither are the aspect of land use.

Production process (L2)
In data from ISOVER, Gullfiber, the regarded loads for production processes of Glass-wool and Stone wool are energy requirements, emissions to air and water and waste to land. Loads associated with construction, renovations and demolition of the factory are not included. Neither are loads associated with production of equipment and machinery used for the production process.

Landfill activities (L3)
In this study, conventional values for energy requirements are the only loads that have been included. There are however many other values and properties that can be included when good data is available.
Emissions related to mechanical work on the deposit site have been calculated according to data for diesel combustion in trucks by Tillman et al., which is presented in table 4.2

Emissions to air	g/MJ consumed fuel
SO2	0,094
NOx	0,9
CO	0,34
CO2	73,4
HC	0,09
Particles	0,1

Table 4.2 Emissions for diesel combustion in lorries (Tillman et al.,1994)

The difference between landfill and other treatment alternatives is the time frame. Emissions from landfills may prevail for a very long time (Finnveden, 2000) and it is therefore important to determine which time period is of interest. Since both glass wool and stone wool can be put on landfill without restrictions it is assumed for this study that the time period does not have a significant influence on the result.

Transports (t1, t2 and t3)
All transportation loads include the energy requirements and emissions to air.
Loads associated with the production of vehicles and other products related to the logistic industry have not been included.

Local distribution transports (<50 km) have been excluded from the study as their impact showed no or very small contribution to the final result. The load for t3 is therefore not regarded for an assessed building situated in the centre of Stockholm, where the deposit site is closer than 50 km.
Energy requirements and emissions related to the material transport (t2) is included and has been calculated with data from BTL-Schenker emission program, which is available at http://www.schenker.nu. This program calculates the amount of energy needed and the emissions produced for a transport with a certain weight going a certain distance.

Construction and demolition are also included as elements in a buildings lifecycle .The loads associated with these processes have however been allocated to the building as a product and not to each material. They are subsequently not regarded here.
If we exclude loads for local distribution transports the total sum of loads become:

$$L_{tot}= L1+t1+L2+t2+L3$$

This sum regards all loads considered in this study, from cradle to grave for a building material that is put on landfill.

4.1.2 Energy recovery system

This system represents the typical recycling system earlier referred to as an *open-loop recycling system*, which was discussed in chapter 2.5.
The studied material is Expanded polystyrene and information on the production has been obtained from the Association of Plastics Manufacturers in Europe (APME). The values for material and energy requirements, emissions to land and water, and waste to land are mean values from three producers in Europe.

Allocation

Using waste as fuel in so-called energy recovery systems, will in most cases cause a higher environmental impact than the case of landfill. It is however suggested in the hierarchy list that this treatment method should be preferred to landfill even though the production of greenhouse gases are significantly higher. The advocates of this recommendation points on the advantages of replacing energy generated from fuels produced from virgin materials, with energy from waste incineration.
This leads us to the method of expanded system boundaries that was discussed in chapter 2.5. This method, allow us to reward an energy recovery system for replacing another fuel. The environmental loads associated with the lifecycle of the replaced fuel is simply subtracted from the total environmental impact of our incinerated material.
The reward will differ significantly in size, depending on which fuel that is replaced by the energy recovery system. This is one of the critical questions that were mentioned in chapter 2.5.4 for the expanded system boundaries. Whether we chose to let the energy recovery system replace energy generated from fossil fuels or bio fuels, will be decisive to the outcome of the study.

In this study the energy generated from incineration of plastic cell insulation has been assumed to replace energy generated from oil combustion. It is mentioned in the product description that incineration of 1 kg EPS plastic produces the same amount of energy as combustion of 1,3 kg oil.
EPS can be regarded as a good addition to the incineration process where several different types of waste are burnt simultaneously.

Since very high temperatures are needed to give a complete combustion, additional fossil fuels with high calorific values are in some cases needed. An addition of EPS plastic insulation does however result in such high temperatures that no or less fossil fuel are needed (APME, 1995). For this reason it has been assumed that EPS plastic insulation replaces fossil fuels to give heat as a second function. Choosing crude oil as the replaced fossil fuel has also seemed logic as EPS is mainly composed of petrochemical products.
Fossil fuels are however not used in all waste incineration plants for maintenance of high temperatures, wherefore this choice might be criticised as a general solution.

In collaboration with Göran Finnveden, who works with the Environmental Strategies Research Group, the expanded system boundary methodology has been adapted to building materials that can be objects for incineration with energy recovery.
The heat generated from this process is supposed to replace heat generated from combustion of oil. All loads allocated to the lifecycle of this oil have been denominated as Ltot*. According to the principles of the expanded system boundary method, Ltot* is subtracted from the assessed lifecycle to give a one-function system.

The assessed lifecycle does consequently only regard the insulating function of the material, as the heat function is eliminated through subtraction of the avoided heat function.
The same system can be used for any type of recycling scenario where the recycled product results in a function 2. In every case this secondary product is assumed to replace another product with the same function.

Ltot for the energy recovery system will thus be;

$$Ltot=L1+t1+L2+t2+L3-Ltot^*$$

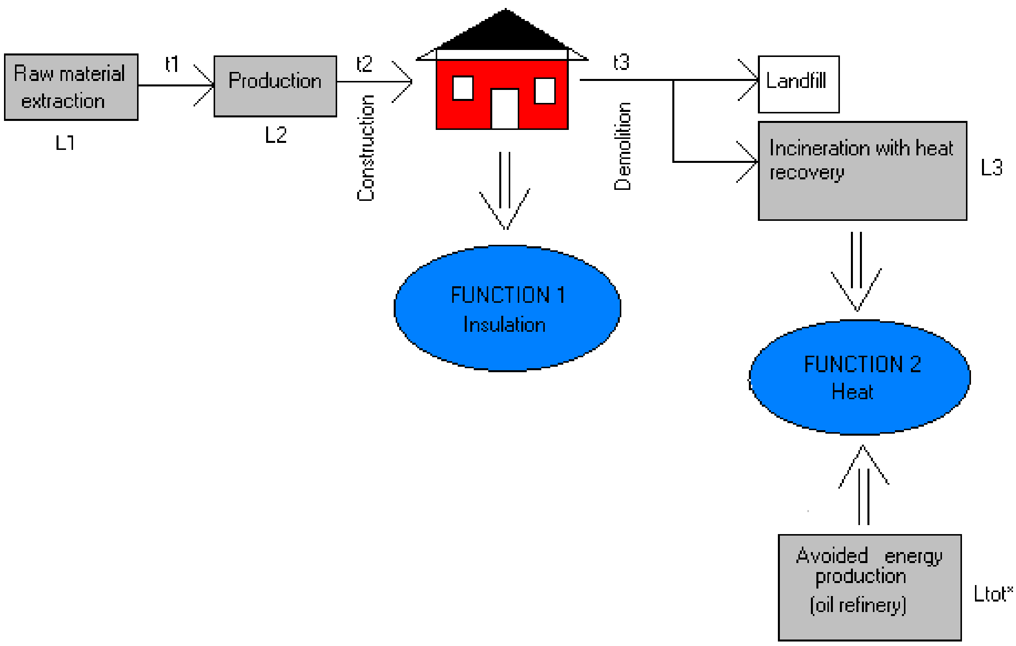

Figure 4.2 Considered loads for a building product that can be incinerated with energy recovery.

System boundaries:
Raw material extraction (L1)
Only the energy use for production of fuels (extraction of oil etc.) are regarded as EPS is produced mainly from petrochemical products.

Production process (L2)
In data from APME the regarded loads for production processes of EPS are energy requirements, emissions to air and water and waste to land.
Loads associated with construction, renovations and demolition of the factory are not included. Neither are loads associated with production of equipment and machinery used for the production process.

Incineration Process (L3)
Data for the incineration of polystyrene plastics was received from the report "Life cycle assessments of energy from solid waste" written by Finnveden et al., 2000.
In these data, consumption of energy and additives are included and electricity consumed at the incineration facility is from coal power. Landfilling of the bottom ash and the fly ash, including transport work, are also included in the system
Loads associated with construction, renovations and demolition of the incineration plant are, however, not included.

Oil refinery and combustion (Ltot)*
Loads associated with oil refinery processes are already existent in the EcoEffect model, and regards resource depletion and emissions to air. This data, with the reference "Nordisk miljövärdering av byggnader", does not regard loads associated with construction, renovations and demolition of refinery plants etc.

Transports (t1, t2 and t3)
Boundaries for transportation loads are the same as for the non-recyclable product system.
The energy requirement and emissions to air in t2 are calculated with the BTL-Schenker emission program and regards the distance from the Termisol company in Täby to the center of Stockholm.
The transportation of plastic wastes from the demolished building to the incineration plant is considered to be a local distribution transport and thus excluded from the calculations.

4.1.3 Reusable product system
When a product is reused, its function remains the same in the next life cycle. This scenario has earlier been referred to as a *closed-loop system*, and has been discussed in chapter 2.5.2.
A product or material can, however, only be reused a certain number of times and must there after be treated in another way.
For the two cellulose fibre materials, eco-fibre and Termoträ, a two-cycle system has been illustrated with landfill as final treatment. It is not very probable that these insulation materials can be reused more than two times and the assumption has therefore seemed logic.

Choosing landfill as the final treatment method might seem a contradiction to what was said earlier about new directives and combustible wastes. A more reasonable choice would have been incineration with heat recovery, but since no emission data for this process is available at this time, the calculations have been impossible to make.

Specific production data have been received from Nordisk Ekofiber (NEF) AB and Svenska Termoträ AB.

Allocation

If we disregard the fact that the quality of the reused material might have been diminished during the first usage period, we receive a system for which the material has exactly the same function two times.
If it is true that Eco fibre and Termoträ have the same insulating capacities after one usage period, than the sum of loads from the first and the second usage period must be divided in two in order to assess only one of the insulating functions.

This means that all loads from cradle to grave will be equally distributed over the cellulose fibre and its reused variant and the total load for each of them is;

$$Ltot = \frac{L1+t1+L2+t2+t3+L3+L4}{2}$$

This is actually the same type of allocation method as "The 50/50 allocation-method", that was described for open-loop systems in chapter 2.5.3. At least as long as we have only two recycling cycles.

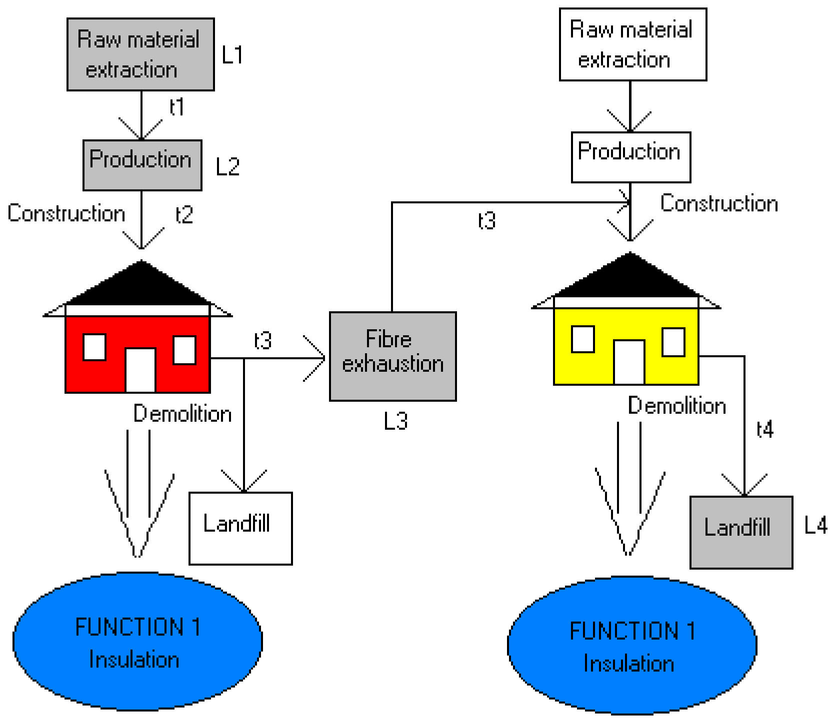

Figure 4.3 Considered loads for Eco-fibre and Termoträ when they are reused once.

It might seem unfair that someone who uses reused eco-fibre or wooden fibres has to pay an equally big environmental price as the one that uses the new product.
The one that uses new insulation must ,however, make sure that it can be reused a second time in order to reduce the total load Ltot with half.

The reused insulation can however never be charged more than half price since the other half has already been paid by the previous user.

System boundaries

Raw material extraction (L1)

The available data from Nordisk Ekofiber (NEF) and Svenska Termoträ is rather general and not very detailed.

The main component of Eco-fibre is recycled newspapers. Loads associated with newspaper production are not regarded in the environmental data from NEF and neither are loads associated with other activities in L1.

The cellulose fibres used in Termoträ comes from pulp. Emissions caused by processes in the pulp factory is included in data from Termoträ AB, but are restricted to the production process only

Loads associated with construction, renovations and demolition of the pulp factory are not included.

Production (L2)

Energy and material requirements for the actual production process are regarded for both materials. Emissions to air are also included in data from NEF but lacking in data from Thermoträ AB. No other loads are considered in L2 for neither of the materials.

Fibre exhaustion with a vacuum suction tube (L3)

In this study specific data for the suction equipment has been received from Waterjet Entreprenad AB and Kurt Eriksson. This company uses vacuum suction cars to remove insulations like eco-fibre or wooden fibres. The suction tube runs on diesel oil and consumes 18 l/h. The car has a container with a volume of 30 m^3, which takes 2-6 h to fill, depending on the circumstances and the construction type (Eriksson, 2001). A mean value of 4h/30 m^3 gives a consumption of 2,4 l/ m^3 exhausted fibres.

The volume of the studied unit is the same for both materials and is 0,26 m^3.

Exhaustion of one studied unit will thus require; 2,4 * 0,26 = 0,624 l diesel

If one litre of MK1 diesel oil has a calorific value of 35,17 MJ (NTM, 2000), then the energy demand for exhausting one functional unit is 0,624 * 35,17 = 21,95 MJ.

Emissions caused by diesel combustion is calculated according to data given in table 4.2 and presented in the next chapter.

Landfill (L4)

Conventional values for energy requirements are the only loads that have been included and emissions have been calculated in the same way as for the non-recyclable system.

Transports (t1, t2, t3 and t4)

Boundaries for transportation loads are the same as for both previous systems.

The energy requirement for t1 is included in product data for Eco-fibre but not for Termoträ.

The load t2 is calculated in the same way as in the two previous systems, using the BTL-Schenker emission program. The Eco-fibre factory is situated in Kallinge, about 500 km from Stockholm. Termoträ is manufactured in Järbro, ca 181 km from Stockholm.

Both t3 and t4 regards local distribution transports wherefore they have been excluded from the final calculations.

4.2 INVENTORY ANALYSIS

All loads have been calculated with respect to the scope and goal definition in the previous section and have been presented on pages 21-26.

SYSTEM: Non-recyclable product system
MATERIAL: **3,84 kg Glass wool, with ρ=16 kg/m³**
TREATMENT METHOD: Landfill

	L1+t1+L2	t2	L3	Ltot
MATERIAL				
Sand	57,6 g			57,6 g
Sodium carbonate	230,4 g			230,4 g
Felspar	614,4 g			614,4 g
Dolomite	96,0 g			96,0 g
Borax	211,2 g			211,2 g
Resin	115,2 g			115,2 g
Urea	38,4 g			38,4 g
Glass	2611,2 g			2611,2 g
Recycled glass wool	38,4 g			38,4 g
Mineral oil	38,4 g			38,4 g
ENERGY				
Processes				
Electricity	37,6 MJ		0,0026 MJ	37,6 MJ
Fossil fuels	29,2 MJ		0,12 MJ	29,32 MJ
Nature gas	39,2 MJ			39,2 MJ
Transports				
MK1 diesel		1,41 MJ		1,41 MJ
EMISSIONS & WASTE				
To air				
CO2	2419,2 g	107,1 g	8,8 g	2535,1 g
NOx	7,7 g	1,1 g	0,1 g	8,9 g
SO2		0,03 g	0,01 g	0,04 g
HC		0,12 g	0,01 g	0,13 g
PM	5,8 g	0,005 g	0,01 g	5,82 g
CO		0,48 g	0,04 g	0,48 g
Ammoniac	11,5 g			11,5 g
Phenol	1,9 g			1,9 g
Formaldehyde	0,019 g			0,019 g
To land				
Industrial waste	76,8 g			76,8 g

* L1+t1+L2: Data for ISOVER Gullfiber glass wool. Missing data: energy demands for transports between cradle and gate (t1) and emissions related to these transports; emissions to air and water when raw materials are extracted.

* t2: Transport energy demand from Billesholm to Stockholm is calculated with BTL Schenker emission program for distances and trucks: 19 km, 24 ton truck Euro 1; 561 km 60 ton truck Euro 1. Program available at http://www.schenker.nu

* L3: Conventional values for energy demand of landfill activities (Tillman et al., 1991). Emissions related to fossil fuel combustion have been calculated for diesel motors according to data from Tillman et al., 1994.

* Ltot = L1+t1+L2+t2+L3

SYSTEM: Non-recyclable product system
MATERIAL: **6,72 kg Stone wool, with ρ=28kg/m^3**
TREATMENT METHOD: Landfill

	L1+t1+L2	t2	L3	Ltot
MATERIAL				
Diabase	8937,6 g			8937,6 g
Dolomite	1276,8			1276,8
Resin	134,4 g			134,4 g
Urea	33,6 g			33,6 g
Recycled stone wool	67,2 g			67,2 g
Mineral oil	33,6 g			33,6 g
ENERGY				
Processes				
Electricity	16,1 MJ		0,0046 MJ	16,15 MJ
Fossile fuels	90,1 MJ		0,22 MJ	90,32 MJ
Transports				
MK1 Diesel		0,46 MJ		0,46 MJ
EMISSIONS & WASTE				
To air				
CO2	7459,2	33,9 g	16,15 g	7509,3 g
NOx	5,04 g	0,34 g	0,20 g	5,58 g
SO2	24,5 g	0,0084 g	0,02 g	24,53 g
HC		0,04 g	0,02 g	0,06 g
PM	1,7 g	0,02 g	0,02 g	1,74 g
CO		0,16 g	0,075 g	0,24 g
Ammoniac	7,1 g			7,1 g
Phenol	0,3 g			0,3 g
Formaldehyde	0,3 g			0,3 g
To land				
Industrial waste	3158,4 g			3158,4 g

* L1+t1+L2: Data for ISOVER Gullfiber stone wool. Missing data: energy demands for transports between cradle and gate (t1) and emissions related to these transports; emissions to air and water when raw materials are extracted.

* t2: Transport energy demand from Vrena to Stockholm is calculated with BTL Schenker emission program for distances and trucks: 108 km 60 ton truck Euro 1. Program available at http://www.schenker.nu

* L3: Conventional values for energy demand of landfill activities (Tillman et al., 1991). Emissions related to fossil fuel combustion have been calculated for diesel motors according to data from Tillman et al., 1994.

* Ltot = L1+t1+L2+t2+L3

SYSTEM: Recycling as energy recovery system
MATERIAL: **3,6 kg EPS- Expanded Polystyrene, with ρ=15 kg/m³**
TREATMENT METHOD: Incineration with energy recovery

	L1+t1+L2	t2	L3	Ltot*	Ltot
MATERIAL					
Iron ore	1,62 g				1,62 g
Limestone	0,79 g				0,79 g
Bauxite	5,76 g				5,76 g
Sodium chloride	43,2 g				43,2 g
Clay	0,072 g				0,072 g
Ferromanganese	0,0036 g				0,0036 g
ENERGY					
Process:Fuels					
Electricity	8,28 MJ			0,91 MJ	7,37 MJ
Coal	3,67 MJ				3,67 MJ
Oil	50,47 MJ			196,9 MJ	146,43 MJ
Gas	48,17 MJ			0,0054 MJ	48,16 MJ
Process:Feedstock					
Coal	0,036 MJ				0,036 MJ
Oil	124,0 MJ				124,0 MJ
Gas	111,8 MJ				111,8 MJ
Transports					
MK1 Diesel		0,13 MJ			0,13 MJ
EMISSIONS & WASTE					
To air					
CO2	6480 g	9,93 g	11484 g	16506,4 g	1457,6 g
NOx	154,8 g	0,10 g	8,53 g	6,13 g	157,3 g
SO2	504 g	0,0025 g		2,53 g	501,5 g
HC	79,2 g	0,011 g			79,2 g
PM	18,4	0,002 g		0,29 g	18,11 g
CO	8,6 g	0,045 g	6,5 g	1,08 g	14,02 g
HS	0,02 g				0,02
HCl	0,14 g				0,14 g
Metals	0,07 g				0,07 g

	L1+t1+L2	t2	L3	Ltot*	Ltot
EMISSIONS & WASTE cont.					
To water					
COD	9,7 g			32,15 g	22,45 g
BOD	0,43 g			1,92 g	1,49 g
Hydrogen ions	0,29 g				0,29 g
Metals	3,6 g			0,026 g	3,57 g
Ammonium	1,4 g				1,4 g
Cloride ions	0,36 g				0,36 g
Dissolved organics	1,15 g				1,15 g
Suspended solids	4,7 g				4,7 g
Oil	1,1 g				1,1 g
HC	2,2 g				2,2 g
Dissolved solids	1,4 g				1,4 g
Nitrogen	0,072 g			0,84 g	0,77 g
Phosphor				0,064 g	0,064 g
CH4				7,35	7,35 g
To land					
Industrial waste	9,4 g				9,4 g
Mineral waste	39,6 g				39,6 g
Slags & ashes	14,4 g			1,09	13,31 g
Toxic chemicals	0,0036 g				0,0036 g
Non-toxic chemicals	25,2 g				25,2 g

* L1+t1+L2: Data from Association of Plastics Manufacturers in Europe (APME), Eco-profile for expanded polystyrene.

* t2: Transport energy demand from Täby to Stockholm is calculated with BTL Schenker emission program for distances and trucks: 29 km, 24 ton truck Euro 1. Program available at http://www.schenker.nu

*L3: Data for incineration of Polystyrene is based on an Organic waste Research (ORWARE) model and is specific for an incineration plant with flue gas condensator. Data has been extracted from the report "Life cycle assessment of energy from solid waste" written by Finnveden et al. 2000.

* Ltot*: Regards environmental loads for refinery and combustion of 4,68 kg oil since 1 kg EPS has the same energetic value as 1,3 kg oil (Thermisol, 2000). Data has been extracted from the report "Olja eller Salix? En jämförande livscykelanalys för elproduktion" written by Ambertsson et al. 1997

* Ltot = L1+t1+L2+t2+L3-Ltot*

SYSTEM: Reusable product system
MATERIAL: **13,52 kg Eco-fibre, with ρ=52 kg/m^3**
TREATMENT METHOD: Reuse

	L1+t1+L2	t2	L3	L4	Ltot
MATERIAL					
Paper from recycled newspapers	11803 g				5901,5 g
Boric acid (H3BO3)	676 g				338 g
Iron oxide	13,52 g				6,76 g
					513,75 g
ENERGY					
Process					
Electricity	47,9 MJ			0,009 MJ	23,95 MJ
Fossil fuels	8,1 MJ		21,95 MJ	0,43 MJ	15,24 MJ
Transport					
MK1 Diesel		5,08 MJ			2,54 MJ
EMISSIONS & WASTE					
To air					
CO2	851,8 g	370 g	1611,13 g	31,56 g	1432,2 g
NOx	2,7 g	3,9 g	19,76 g	0,39 g	26,75 g
SO2	0,76 g	0,09 g	2,06 g	0,04 g	1,475 g
HC	0,73 g	0,42 g	1,98 g	0,039 g	1,58 g
PM	0,81 g	0,07 g	2,2 g	0,043 g	1,56 g
CO	2,76 g	1,7 g	7,46 g	0,15 g	6,04 g

* L1+t1+L2: Data from Nordiska Ekofiber NEF AB. Data has been complemented with calculated values for emissions related to transportations in t1, according to data from Tillman et al., 1994.

* t2: Transport energy demand from Kallinge to Stockholm is calculated with BTL Schenker emission program for distances and trucks: 32 km, 24 ton truck Euro 1; 535 km, 60 ton truck Euro 1. Program available at http://www.schenker.nu

*L3: Exhaustion of insulating fibres is done with a vacuum suction tube that runs on diesel. Data has been received from Water Jet entrepreneurs AB and Kurt Eriksson.

*L4: Conventional values for energy demand of landfill activities (Tillman et al., 1991). Emissions related to fossil fuel combustion have been calculated for diesel motors according to data from Tillman et al., 1994.

* Ltot = [L1+t1+L2+L3+L4]/2

SYSTEM: Reusable product system
MATERIAL: **12,48 kg Termoträ, with ρ=48 kg/m^3**
TREATMENT METHOD: Reuse

	L1+t1+L2	t2	L3	L4	Ltot
MATERIAL					
Pulp	11853,5 g				5926,75 g
Ammonium polyphosphate	624 g				312 g
Boric acid (H3BO3)	2,5 g				1,25 g
ENERGY					
Process					
Electricity	6,33 MJ			0,0085 MJ	3,17 MJ
Fossil fuels	55,4 MJ		21,95 MJ	0,40 MJ	38,9 MJ
Transport					
MK1 Diesel		1,41 MJ			0,705 MJ
EMISSIONS & WASTE					
To air					
CO2	4380,5 g	104,5 g	1611,13 g	29,36 g	3062,7 g
NOx	6,6 g	1,07 g	19,76 g	0,36 g	13,9 g
SO2	6 g	0,024 g	2,06 g	0,038 g	4,06 g
HC		0,11 g	1,98 g	0,036 g	1,06 g
PM	6,6 g	0,02 g	2,2 g	0,04 g	4,43 g
CO		0,48 g	7,46 g	0,14 g	4,28 g
To water					
COD	423,3g				211,7 g
BOD	45,3 g				22,7 g
SS	8,2 g				4,1 g
Phosphor	0,9 g				0,45 g
Nitrogen	6 g				3 g
To land					
Industrial waste	299,5				149,8 g

* L1+t1+L2: Data from Svenska Termoträ AB. Missing data: energy demands for transports between cradle and gate (t1) and emissions related to these transports.

* t2: Transport energy demand from Järbo to Stockholm is calculated with BTL Schenker emission program for distances and trucks: 178 km, 60 ton truck Euro 1. Program available at http://www.schenker.nu

*L3: Exhaustion of insulating fibres is done with a vacuum suction tube that runs on diesel. Data has been received from Water Jet entrepreneurs AB and Kurt Eriksson.

*L4: Conventional values for energy demand of landfill activities (Tillman et al., 1991). Emissions related to fossil fuel combustion have been calculated for diesel motors according to data from Tillman et al., 1994.

* Ltot = [L1+t1+L2+L3+L4]/2

4.3 IMPACT ASSESSMENT

The impact assessment step has been performed with the EcoEffect model, which is based on the database program Access 97 from Microsoft.

Since the main function of the model is to assess entire buildings and not single materials, some data regarding the building in which the material is used was required.
Since one of the existing reference buildings in the model contained 14,7 ton glass wool, the amount of studied units could be calculated from that value. If one studied unit glass wool weighs 3,84 kg, than a building with 14,7 ton glass wool has; 14700/3,84 = 3828,13 studied units. This means that the assessed building has 3828,13 m^2 of insulated walls.
By relating the modelled building to the reference building, the rest of the data concerning resident number, living area etc. could be copied from the reference building.
This basic information has been presented in appendices 1 and 2.

After defining the general properties of the building, the materials could be assessed one after one, in the part of the model concerning material impacts.
Some compromises has, however, been required, due to lack of data in the EcoEffect database.
The only considered loads from the inventory analysis was energy requirements and emission to air. Loads regarding raw material input, emissions to water and waste to land have consequently not been assessed.
Loads concerning waste to land and emission to water that is present in the figures are related to the energy requirements and is calculated by the EcoEffect program. One example is radioactive waste that is related to electricity loads.
The box for natural resources is empty for all materials assessed, even though the requirements of non renewable resources such as crude oil has been regarded for all materials. The lack of connection between data inputs for energy and the registration of natural resource depletion in the EcoEffect model is the reason for that.
Relative impact values in figures 4.4-4.9 regards the potential environmental impact per resident relative the average impact per capita.

Figure 4.4 Relative impact of Glass wool

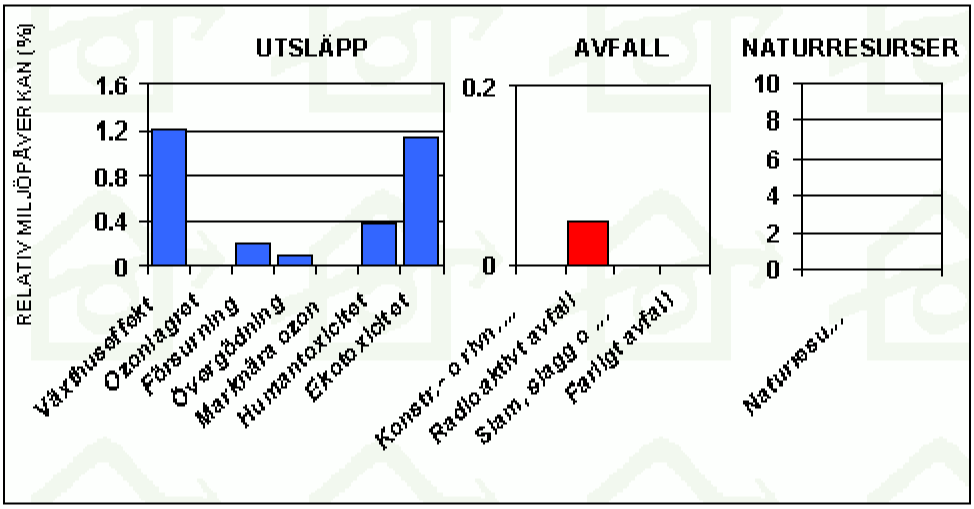

Figure 4.5 Relative impact of Stone wool

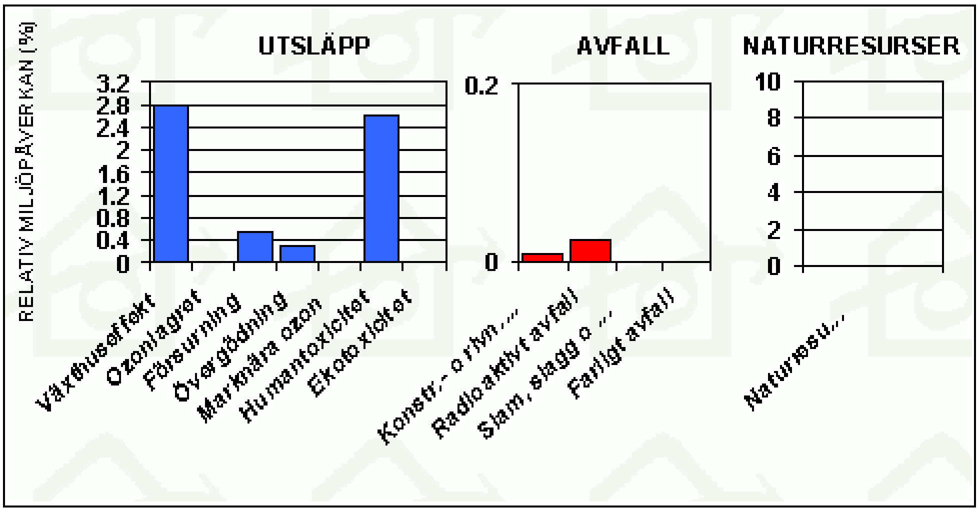

Figure 4.6 Relative impact of EPS without subtraction of an avoided load (L1+t1+L2+t2+L3)

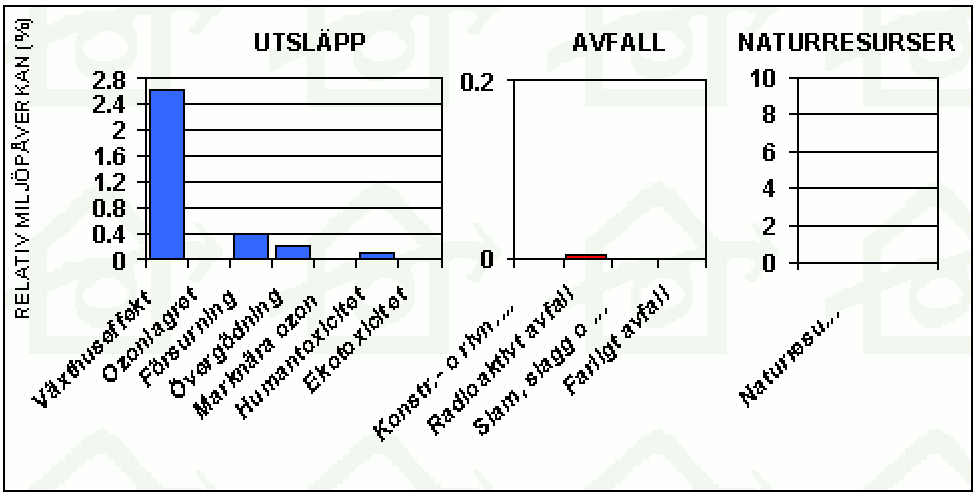

Figure 4.7 Relative impact of refinery and combustion of crude oil (Ltot)*

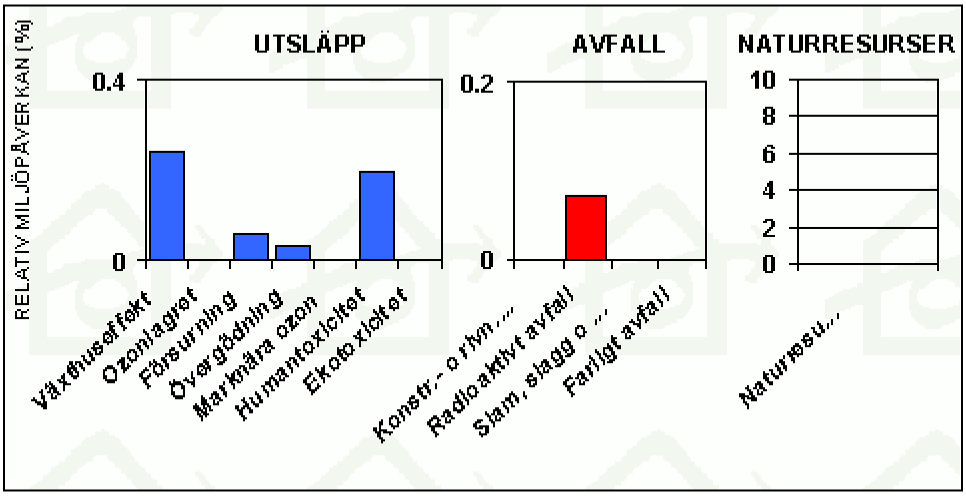

Figure 4.8 Relative impact of Eco-fibre

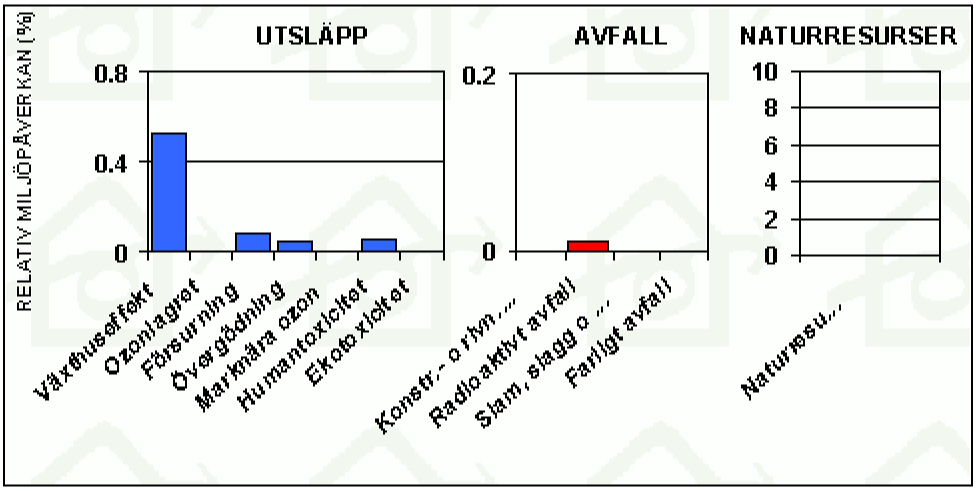

Figure 4.9 Relative impact of Termoträ

More detailed information regarding load contributions and effect factors for each effect category is available in appendices 3-9.

4.4 RESULT INTERPRETATION

In the case of EPS it was necessary to first assess the actual lifecycle of EPS when it is incinerated and thereafter the load for the avoided fuel. This is caused by the fact that some loads become negative when Ltot* is subtracted and it is not possible to assess a negative load.

Instead of subtracting every load separately, it is possible to subtract the relative impact value of each effect category. This was done in Excel and the resulting chart has been illustrated in figure 4.10.

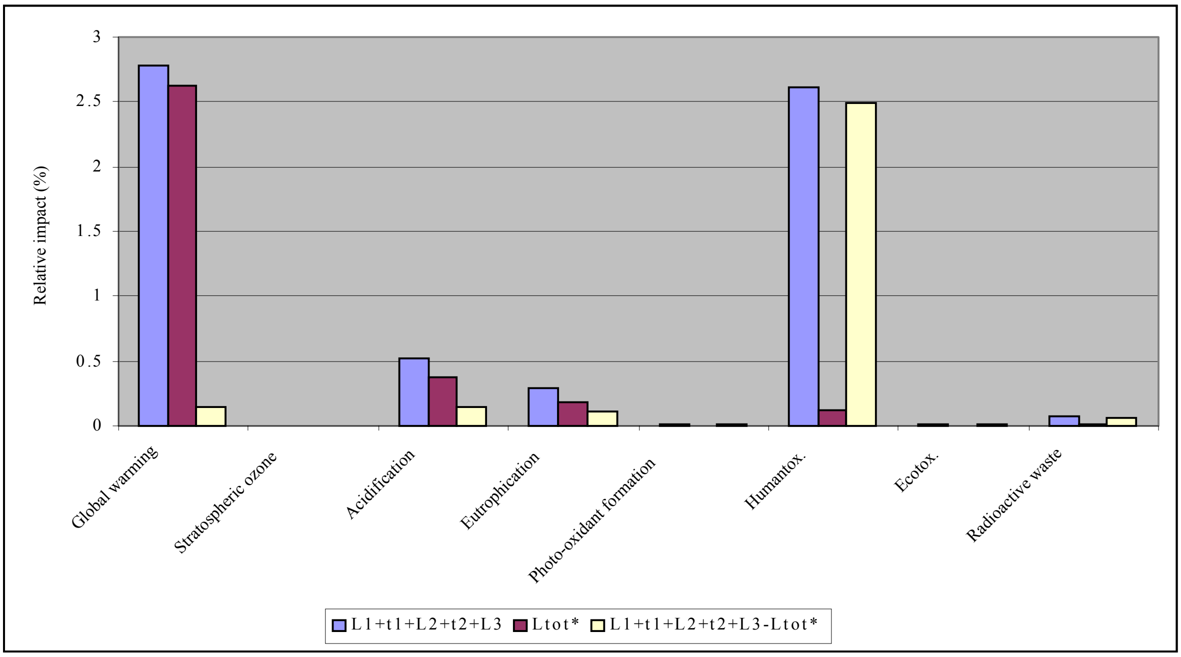

Figure 4.10 Relative impact of EPS when the avoided load is subtracted

Subtracting environmental loads associated with refinery and combustion of oil will strongly affect the impact categories that are represented by fossil fuel emissions such as carbon dioxide. The relative impact value for global warming has consequently been greatly reduced since carbon dioxide is the main load regarded in this category.

Loads considered in the human toxicological effect category are mainly associated with the electricity used as energy source. Subtracting the mentioned loads will consequently not have a large reducing effect on this effect category.

In order to compare the relative environmental effect of each material, a second chart was made in Excel, which is shown in figure 4.11.

It is important to remember that the comparison only regards loads related to energy requirements and emissions to air. It is also important to remember that each value is calculated with respect to allocation methods and boundary settings chosen by he author. Data quality is another decisive factor that is discussed later in this chapter.

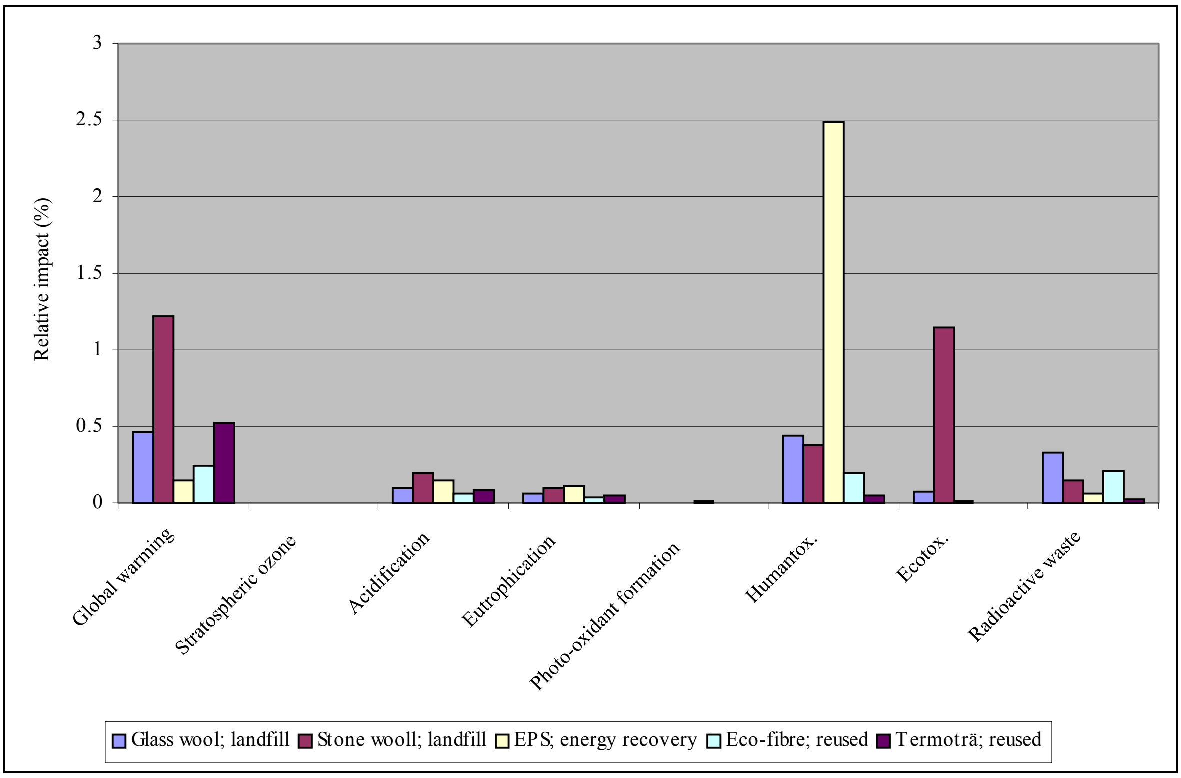

Figure 4.11 Summary of relative environmental impacts for different insulation materials

The relationships between data input and output for the different insulation materials, becomes clear when we study the tables in appendices 3-9,
The size of the global warming effect category is proportional to the amount of carbon dioxide that can be related to the assessed lifecycle. Other gases such as methane, carbon monoxide and halone are also contributing to this effect category but are not emitted in the same amounts.
Carbon dioxide is together with water one of the main products from fossil fuel combustion and is therefore practically proportional to the fossil fuel requirements of a system.
EPS is a petrochemical product using large quantities of fossil fuels such as oil, gas and coal, both as energy sources and as raw material. This insulation material does however show a very low contribution to the global warming effect after subtracting the avoided load Ltot*.
Stone wool is therefore the insulation material with the highest contribution to the global warming effect, which is caused by the high temperature needs for the production process.

Loads contributing to the acidification category are mainly sulphur dioxide and ammoniac. Sulphur dioxide is like carbon dioxide, strongly related to the fossil fuel requirements. Ammoniac is mainly emitted from the mineral wool production processes where it can be traced back to urea.

Nutrient enrichment is mainly caused by nitrogen oxides and phosphor that ends up in water where they contribute to an excessive growth of living plant material.
The relative impact to this effect category is more or less the same for the different materials.

The high relative impact of EPS to the human toxicological impact category is mainly caused by loads associated with the electricity source. Benzene, nitrogen oxides, sulphur dioxides and carbon monoxide are some of the loads that have been considered for the "Swedish electricity mixture", which has been used in the calculations. In appendix 5, it is clear that benzene and nitrogen oxides are the main contributors to the impact value. The amount of radioactive waste is also proportional to the electricity demand since 48% of the energy provided from Swedish electricity mixture has a nuclear origin (according to the EcoEffect program).

For the cellulose fibres it becomes clear that Termoträ have higher fossil fuel demands and is thus contributing to the global warming more than Eco-fibre. On the other hand, the production of Eco-fibre causes higher human toxicological effects due to larger electricity requirements.
Metal loads are also contributing to the human toxicological effect.

The eco-toxicological effects caused by the production process of stone wool, is mainly caused by emitted formaldehyde. Also the production process of glass wool contributes to this effect category with a smaller amount of formaldehyde.

It is evident that allowing subtraction of avoided loads, through system expansion, will favour the studied material. In the case of EPS and the energy recovery system it is clear for the categories regarding global warming, acidification and eutrophication. The size of the reward is naturally dependent on the choice of loads that shall be subtracted. This choice can never be wrong or right, only more or less fair.
The subtracted loads were in this case quite large, but choosing crude oil to represent the avoided fuel has been defended earlier in this report.

An interesting question is if it is environmentally favourable to reuse cellulose fibre insulations, instead of depositing them after one usage period.
The loads that can be related to a landfill scenario are shown in figure 4.12, together with the impact values related to the reuse scenario. The results are more or less the same for both Termoträ and Eco-fibre, wherefore only one example have been illustrated.

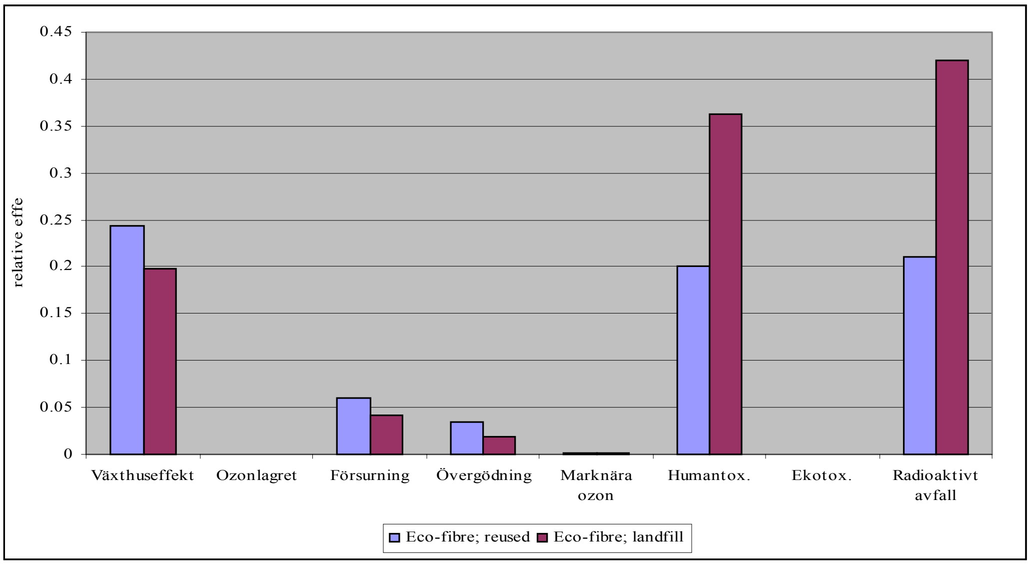

Figure 4.12 Relative impact of Eco-fibre in a landfill scenario versus the reusing scenario

The exhaustion process demands a great amount of diesel wherefore the relative global warming effect will be strongly affected. Other emissions related to diesel combustion are sulphur dioxide and nitrogen oxides, and the categories acidification and nutrient enrichment

are therefore also affected by this process. The total electricity demand is half for a reused product according to the 50/50-method and the toxicological effects on humans and the amount of radioactive waste are consequently reduced with almost 50% as well. The correlation between these two parameters were discussed earlier.
There are consequently both advantages and disadvantages with reusing cellulose fibres.

If a weighting step had been performed as well, it would have been possible make a statement about the seriousness of the different effects. This last step of the lifecycle assessment have been excluded in this study as weighting factors are under development in the EcoEffect model and not yet applicables.

Data quality and uncertainty
The data used in this study has been of varying quality
Information about production processes and loads associated with them, have been received from each manufacturer and are more or less detailed. Materials like EPS and mineral wool presents much more detailed data, whereas environmental data received from Termoträ AB and Eco-fiber AB is more general.
These aspects will affect the accuracy of the LCA results and consequently the whole outcome of the study.
Conclusions must therefore be drawn most cautiously.

5. CONCLUSIONS AND DISCUSSION

5.1 CONCLUSIONS

The following conclusions have been drawn during the proceeding of this study:

*** Several methods to calculate environmental loads in recycling systems must be tested in order to suggest a procedure, that best follows the goals and aims of EcoEffect.**
In this study only the method with expanded system boundaries was tested for open-loop recycling systems.
It would have been valuable to test all allocation methods, using data for only one material and treatment method at a time.

***The choice of avoided product is decisive to the outcome of the study when the method of expanded system boundaries is applied.**
In this study heat generated from incineration of EPS was regarded a substitution for heat produced from combustion of crude oil. This resulted in a very large effect reduction, which might seem unfair to the other materials. If the avoided heat source had been any of the renewable energy sources, the result had been completely different.

***It is only possible to speculate about the environmental soundness of the studied insulation materials.**
Due to lack of data, the study was focused on the energy requirements and the emissions to air. Since all effects have not been included, it is impossible to make statements about the advantages and disadvantages of using one material over another.
The difference in data quality is another influence that must be regarded before commenting on the relative impacts of the materials.
It is consequently impossible to say that mineral wool should be replaced by cellulose fibres, even though the results are pointing in that direction.

***The relative impact associated with different energy carriers are based on available information in the EcoEffect database.**
Results depend on which loads that have been considered for the specific carrier, in the database of the computerised assessment tool.
The loads associated with the Swedish electricity mixture is for example dependent on the proportions of nuclear power, wind power, hydro power etc.

*** Depending on what energy source that is used in raw material extraction-, production- and recycling processes, the effects on the environment will be different.**
Global warming is caused mainly by fossil fuel combustion while electricity consuming processes lead to higher human toxicological impacts and radio active waste. These trends are in their turn dependent on the information that is stored in the EcoEffect database.

*** If reuse of cellulose fibres shall be favourable to the environment, the exhaustion process must be performed with another fuel source than diesel.**
The diesel requirements for the exhaustion process results in higher relative effects for some of the effect categories, when the fibres are reused instead of put on landfill. These effects could be reduced if another, renewable fuel was used instead of diesel.

5.2 DISCUSSION

Modelling product systems is a most complicated task that can drive a person more or less crazy.
The final result depends on so many choices and assumptions made along the way and can therefore send completely different signals from one case to another.
Every result is dependent on the goal and scope of the study and also on the instruments and data used in the impact assessment step.
As with a puzzle, all pieces must be present before the whole picture can be seen. It is always possible to speculate in the form and colour of missing pieces, but it is important to remember how the picture was received.

If I had the power to turn back time and do this work over again I would. There are a few things that I would have liked to change or do better.
First of all I would have dealt with one variable at a time instead of testing two simultaneously.
Different allocation methods would first have been tested fore one material and recycling form. The method that best followed the aims and goals of EcoEffect would thereafter be used in a second step. Here materials and recycling alternatives would be the variables while the chosen allocation method would be held constant.

In order to enhance the quality of the results I would also have liked to:
1. Investigate inputs and outputs from the studied systems on a more detailed level, in order to get good and more comparable measurements. All loads related to a system could then be regarded in the impact assessment step and it would be possible to draw more accurate conclusions.
2. Develop the EcoEffect database so that all loads can be included in the assessment step.

BUT, since I do not possess the power to rule over time I have to settle with the results I have received in this study. I still regard myself as very successful in my work, since I have learned more about LCA than I thought was possible in four months.

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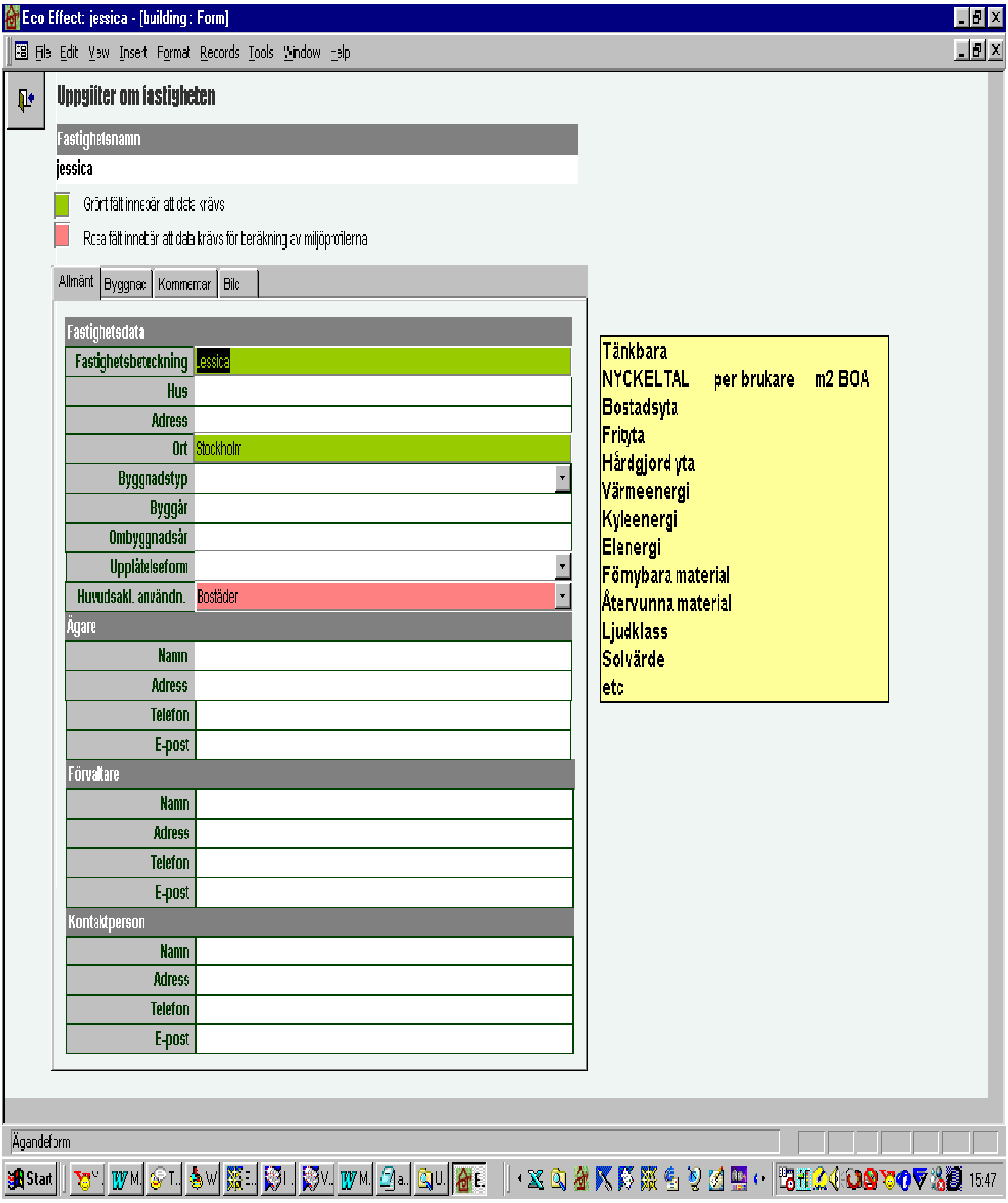
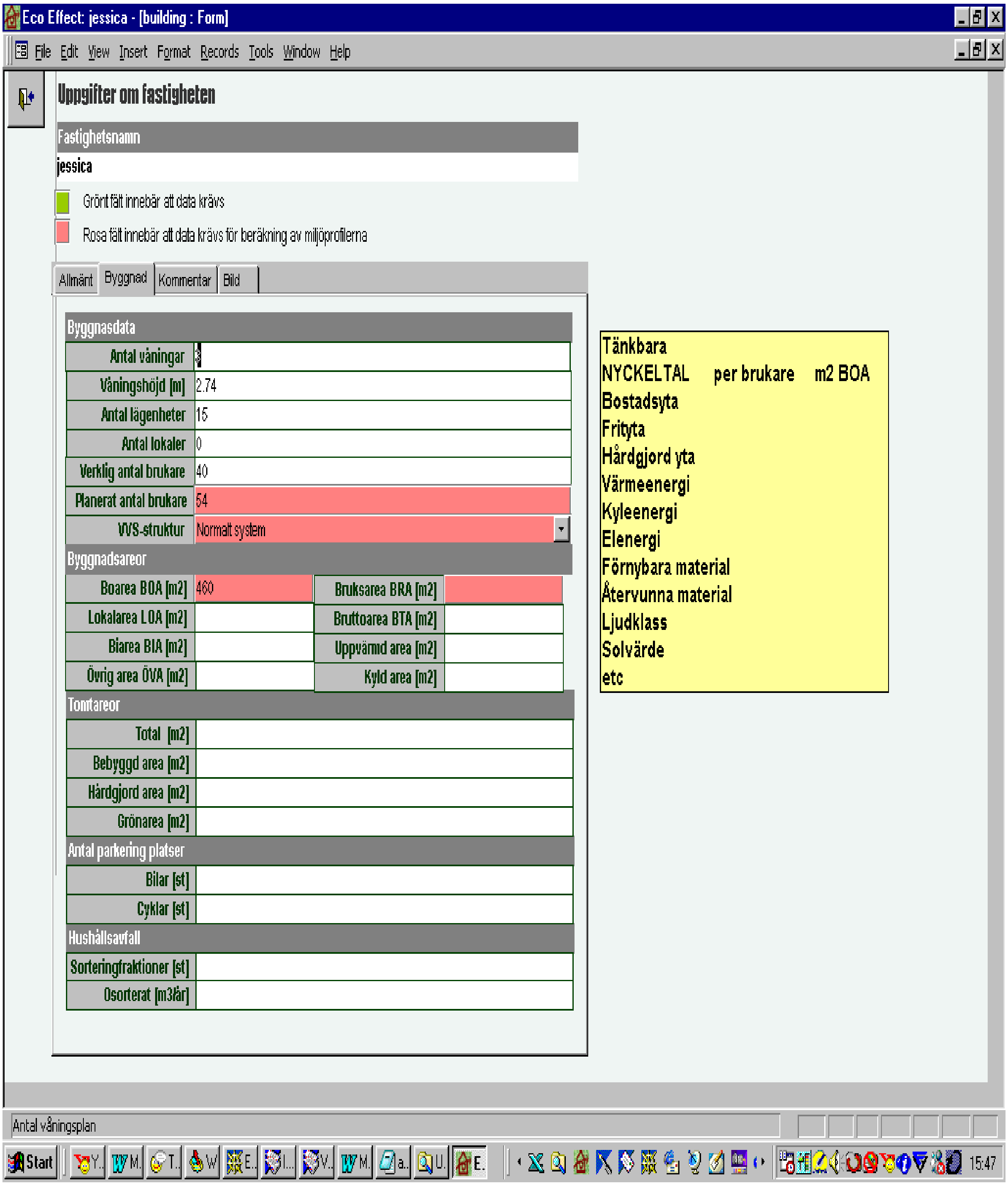
Lagerling, Per: Nordiska Ekofiber NEF AB. Tel.: 08-564 720 99
Nilsson, Roland: Rivners AB. Tel.: 0709-712733
Partheen, Klas: Paroc. Tel.: 0420-84195
Sundin, Jan: Svenska Termoträ AB. Tel.: 0290-623 42

Appendix 1. EcoEffect building form



Appendix 2 EcoEffect building form



Appendix 3. Environmental effect data for glass wool, calculated by EcoEffect:

name2	amount	weighting.name	effectFactor	Uttryck1
Ammoniak	11.50	Acidification	1.88	21.62
Fluorsyra	0.0035	Acidification	1.6	0.0057
Nitrogen oxides	58.40	Acidification	0.7	40.88
Sulfat	0.57	Acidification	1	0.57
Sulfid	0.00026	Acidification	1	0.00026
Svaveldioxid	21.12	Acidification	1	21.120
Svaveloxider	5.98	Acidification	1	5.98
Konstruktions och rivningsavfall	3.84	Bulk Waste	1	3.84
Benzene	0.00157	Ecotoxicity	3.6	0.0057
Benzene	0.00158	Ecotoxicity	4	0.0063
Cadmium	1.8269E-06	Ecotoxicity	1.8	0.0000033
Cadmium	1.83E-06	Ecotoxicity	24000	4.38E-02
Formaldehyde	0.019	Ecotoxicity	24	0.456
Formaldehyde	0.019	Ecotoxicity	200	3.8
Phenol	9.13E-05	Ecotoxicity	22	2.009E-03
Phenol	9.134E-05	Ecotoxicity	44	4.02E-03
Toluene	0.0009776	Ecotoxicity	0.97	0.000948
Toluene	0.0009776	Ecotoxicity	4	0.0039
Toluene	0.0009776	Ecotoxicity	10	0.00978
Carbon dioxide	28453.18	Global Warming	1	28453.185
Carbon monoxide	3.212	Global Warming	2	6.42
Halon 1301	0.0000376	Global Warming	5600	0.21
Lustgas	0.378	Global Warming	320	120.87
Metan	1.076	Global Warming	25	26.89
Benzene	0.001579	Human toxicity	2.3	0.0036
Benzene	0.001579	Human toxicity	14	0.022
Benzene	0.001579	Human toxicity	10000000	15792
Cadmium	1.827E-06	Human toxicity	4.5	0.0000082
Cadmium	1.83E-06	Human toxicity	560	1.0231E-03
Cadmium	1.83E-06	Human toxicity	110000000	200.96
Carbon monoxide	3.21	Human toxicity	830	2666.30
Formaldehyde	0.019	Human toxicity	0.000022	0.000000418
Formaldehyde	0.019	Human toxicity	0.0058	0.00011
Formaldehyde	0.019	Human toxicity	13000000	247000
Nitrogen oxides	58.40	Human toxicity	8600	502260.59
Phenol	9.13E-05	Human toxicity	0.034	3.11E-06
Phenol	1.9	Human toxicity	1400000	2660000
Silver	0.034	Human toxicity	5.3	0.178

Toluene	0.00098	Human toxicity	0.001	0.000000978
Toluene	0.00098	Human toxicity	0.004	0.00000391
Toluene	0.00098	Human toxicity	2500	2.44
Ammoniak	11.50	Nutrient Enrichment	3.64	41.86
Cyanid	0.0000376	Nutrient Enrichment	2.38	0.000089
Lustgas	0.378	Nutrient Enrichment	2.82	1.065
Nitrat	0.0078	Nutrient Enrichment	1	0.0078
Nitrogen oxides	58.40	Nutrient Enrichment	1.35	78.84
Total N	0.0090	Nutrient Enrichment	4.43	0.0398
Total P	0.0057	Nutrient Enrichment	32.03	0.181
Halon 1301	0.0000376	Ozone Depletion	12	0.00045
Benzene	0.0015792	Ozone Production	0.2	0.00031
Carbon monoxide	3.212	Ozone Production	0.03	0.096
Formaldehyde	0.019	Ozone Production	0.4	0.0076
Metan	1.08	Ozone Production	0.007	0.00753
Toluene	0.000978	Ozone Production	0.6	0.0005
Radioactive waste	18.04	Radioactive Waste	1	18.04
Slagg och aska	0.548	Slag and Ashes	1	0.548

Appendix 4. Environmental effect data for Stone wool, calculated by EcoEffect;

name2	amount	weighting.name	effectFactor	Uttryck1
Ammoniak	7.10043605	Acidification	1.88	13.348819774
Fluorsyra	0.0015181	Acidification	1.6	0.00242896
Nitrogen oxides	132.278567583333	Acidification	0.7	92.5949973083334
Sulfat	0.24548	Acidification	1	0.24548
Sulfid	0.00011305	Acidification	1	0.00011305
Svaveldioxid	60.5200000000001	Acidification	1	60.5200000000001
Svaveloxider	2.56785	Acidification	1	2.56785
Benzene	0.0006783	Ecotoxicity	3.6	0.00244188
Benzene	0.0006783	Ecotoxicity	4	0.0027132
Formaldehyde	0.3	Ecotoxicity	24	7.2
Formaldehyde	0.3	Ecotoxicity	200	60
Toluene	0.0004199	Ecotoxicity	0.97	0.000407303
Toluene	0.0004199	Ecotoxicity	4	0.0016796
Toluene	0.0004199	Ecotoxicity	10	0.004199
Carbon dioxide	74604.0913768668	Global Warming	1	74604.0913768668
Carbon monoxide	0.82509835	Global Warming	2	1.6501967
Halon 1301	0.00001615	Global Warming	5600	0.09044
Lustgas	0.0052972	Global Warming	320	1.695104
Metan	0.4620515	Global Warming	25	11.5512875
Benzene	0.0006783	Human toxicity	2.3	0.00156009
Benzene	0.0006783	Human toxicity	14	0.0094962
Benzene	0.0006783	Human toxicity	10000000	6783
Carbon monoxide	0.82509835	Human toxicity	830	684.8316305
Formaldehyde	0.3	Human toxicity	0.000022	0.0000066
Formaldehyde	0.3	Human toxicity	0.0058	0.00174
Formaldehyde	0.3	Human toxicity	13000000	3900000
Nitrogen oxides	132.278567583333	Human toxicity	8600	1137595.68121667
Phenol	0.3	Human toxicity	1400000	420000
Silver	0.0144058	Human toxicity	5.3	0.07635074
Sulphur dioxide	24.53	Human toxicity	1300	31889
Toluene	0.0004199	Human toxicity	0.001	0.0000004199
Toluene	0.0004199	Human toxicity	0.004	0.0000016796
Toluene	0.0004199	Human toxicity	2500	1.04975
Ammoniak	7.10043605	Nutrient Enrichment	3.64	25.845587222
Cyanid	0.00001615	Nutrient Enrichment	2.38	0.000038437
Lustgas	0.0052972	Nutrient Enrichment	2.82	0.014938104
Nitrat	0.00334305	Nutrient Enrichment	1	0.00334305
Nitrogen oxides	132.278567583333	Nutrient Enrichment	1.35	178.5760662375

Total N	0.00385985	Nutrient Enrichment	4.43	0.0170991355
Total P	0.00243865	Nutrient Enrichment	32.03	0.0781099595
Halon 1301	0.00001615	Ozone Depletion	12	0.0001938
Benzene	0.0006783	Ozone Production	0.2	0.00013566
Carbon monoxide	0.82509835	Ozone Production	0.03	0.0247529505
Formaldehyde	0.3	Ozone Production	0.4	0.12
Metan	0.4620515	Ozone Production	0.007	0.0032343605
Toluene	0.0004199	Ozone Production	0.6	0.00025194
Radioactive waste	7.752	Radioactive Waste	1	7.752

Appendix 5. Environmental effect data for EPS without the reduction for Ltot*, calculated by EcoEffect;

name2	amount	weighting.name	effectFactor	Uttryck1
Ammoniak	0.00582251	Acidification	1.88	0.0109463188
Fluorsyra	0.00221805	Acidification	1.6	0.00354888
Nitrogen oxides	449.528789773333	Acidification	0.7	314.670152841333
Saltsyra	0.15775667	Acidification	0.88	0.1388258696
Sulfat	13.339378	Acidification	1	13.339378
Sulfid	0.0019776	Acidification	1	0.0019776
Svaveldioxid	118.566330833333	Acidification	1	118.566330833333
Svaveloxider	8.899098	Acidification	1	8.899098
Svavelväte	0.02	Acidification	1.88	0.0376
Konstruktions och rivningsavfall	88.1681500000002	Bulk Waste	1	88.1681500000002
Arsenic	3.02983333333334E-05	Ecotoxicity	0.27	8.18055000000002E-06
Arsenic	3.02983333333334E-05	Ecotoxicity	380	1.15133666666667E-02
Benzene	0.11856559	Ecotoxicity	3.6	0.426836124
Benzene	0.11856559	Ecotoxicity	4	0.47426236
Cadmium	3.02983333333334E-06	Ecotoxicity	1.8	5.45370000000001E-06
Cadmium	3.02983333333334E-06	Ecotoxicity	24000	7.27160000000002E-02
Chromium	1.51491666666667E-05	Ecotoxicity	0.01	1.51491666666667E-07
Chromium	1.51491666666667E-05	Ecotoxicity	130	1.96939166666667E-03
Copper	3.02983333333334E-05	Ecotoxicity	0.02	6.05966666666668E-07
Copper	3.02983333333334E-05	Ecotoxicity	2500	7.57458333333335E-02
Lead	3.02983333333334E-05	Ecotoxicity	0.01	3.02983333333334E-07
Lead	3.02983333333334E-05	Ecotoxicity	400	1.21193333333334E-02
Mercury	6.05966666666668E-06	Ecotoxicity	0.01	6.05966666666668E-08
Mercury	6.05966666666668E-06	Ecotoxicity	4000	2.42386666666667E-02
Nickel	0.00002272375	Ecotoxicity	0.05	0.0000011361875
Nickel	0.00002272375	Ecotoxicity	130	2.95408750000001E-03
Selenium	1.21193333333334E-05	Ecotoxicity	106	1.28464933333334E-03
Selenium	1.21193333333334E-05	Ecotoxicity	4000	4.84773333333334E-02
Toluene	0.00133507	Ecotoxicity	0.97	0.0012950179
Toluene	0.00133507	Ecotoxicity	4	0.00534028
Toluene	0.00133507	Ecotoxicity	10	0.0133507
Vanadium	4.54475000000001E-05	Ecotoxicity	0.34	0.00001545215
Vanadium	4.54475000000001E-05	Ecotoxicity	40	0.0018179
Zinc	1.51491666666667E-04	Ecotoxicity	0.005	7.57458333333335E-07
Zinc	1.51491666666667E-04	Ecotoxicity	200	3.02983333333334E-02
Carbon dioxide	168964.26350044	Global Warming	1	168964.26350044

Carbon monoxide	23.4013411166667	Global Warming	2	46.8026822333333
Halon 1301	0.00000828	Global Warming	5600	0.046368
Lustgas	0.1769091	Global Warming	320	56.610912
Metan	50.60312536	Global Warming	25	1265.078134
Arsenic	3.02983333333334E-05	Human toxicity	7.4	2.24207666666667E-04
Arsenic	3.02983333333334E-05	Human toxicity	100	3.02983333333334E-03
Arsenic	3.02983333333334E-05	Human toxicity	9500000	287.834166666667
Benzene	0.11856559	Human toxicity	2.3	0.272700857
Benzene	0.11856559	Human toxicity	14	1.65991826
Benzene	0.11856559	Human toxicity	10000000	1185655.9
Cadmium	3.02983333333334E-06	Human toxicity	4.5	0.00001363425
Cadmium	3.02983333333334E-06	Human toxicity	560	1.69670666666667E-03
Cadmium	3.02983333333334E-06	Human toxicity	110000000	333.281666666667
Carbon monoxide	23.4013411166667	Human toxicity	830	19423.1131268333
Chromium	1.51491666666667E-05	Human toxicity	1.1	1.66640833333334E-05
Chromium	1.51491666666667E-05	Human toxicity	3.6	5.45370000000001E-05
Chromium	1.51491666666667E-05	Human toxicity	1000000	15.1491666666667
Copper	3.02983333333334E-05	Human toxicity	0.004	1.21193333333334E-07
Copper	3.02983333333334E-05	Human toxicity	3.4	1.03014333333334E-04
Copper	3.02983333333334E-05	Human toxicity	570	0.01727005
Lead	3.02983333333334E-05	Human toxicity	0.083	2.51476166666667E-06
Lead	3.02983333333334E-05	Human toxicity	53	1.60581166666667E-03
Lead	3.02983333333334E-05	Human toxicity	100000000	3029.83333333334
Mercury	6.05966666666668E-06	Human toxicity	81	4.90833000000001E-04
Mercury	6.05966666666668E-06	Human toxicity	110000	0.666563333333335
Mercury	6.05966666666668E-06	Human toxicity	6700000	40.5997666666668
Nickel	0.00002272375	Human toxicity	0.0037	8.40778750000002E-08
Nickel	0.00002272375	Human toxicity	0.12	2.72685000000001E-06
Nickel	0.00002272375	Human toxicity	67000	1.52249125
Nitrogen oxides	449.528789773333	Human toxicity	8600	3865947.59205067
Selenium	1.21193333333334E-05	Human toxicity	0.044	5.33250666666668E-07
Selenium	1.21193333333334E-05	Human toxicity	28	3.39341333333334E-04
Selenium	1.21193333333334E-05	Human toxicity	1500000	18.179
Silver	0.00738576	Human toxicity	5.3	0.039144528
Sulphur dioxide	504	Human toxicity	1300	655200
Toluene	0.00133507	Human toxicity	0.001	0.00000133507
Toluene	0.00133507	Human toxicity	0.004	0.00000534028
Toluene	0.00133507	Human toxicity	2500	3.337675
Vanadium	4.54475000000001E-05	Human toxicity	0.037	0.0000016815575
Vanadium	4.54475000000001E-05	Human toxicity	0.96	4.36296000000001E-05

Vanadium	4.54475000000001E-05	Human toxicity	140000	6.36265000000001
Zinc	1.51491666666667E-04	Human toxicity	0.013	1.96939166666667E-06
Zinc	1.51491666666667E-04	Human toxicity	4.1	6.21115833333335E-04
Zinc	1.51491666666667E-04	Human toxicity	81000	12.270825
Ammoniak	0.00582251	Nutrient Enrichment	3.64	0.0211939364
Cyanid	0.00192792	Nutrient Enrichment	2.38	0.0045884496
Lustgas	0.1769091	Nutrient Enrichment	2.82	0.498883662
Nitrat	0.00315369	Nutrient Enrichment	1	0.00315369
Nitrogen oxides	449.528789773333	Nutrient Enrichment	1.35	606.863866194
Total N	0.00389856	Nutrient Enrichment	4.43	0.0172706208
Total P	0.15370169	Nutrient Enrichment	32.03	4.9230651307
Halon 1301	0.00000828	Ozone Depletion	12	0.00009936
Benzene	0.11856559	Ozone Production	0.2	0.023713118
Carbon monoxide	23.4013411166667	Ozone Production	0.03	0.7020402335
Metan	50.60312536	Ozone Production	0.007	0.35422187752
Toluene	0.00133507	Ozone Production	0.6	0.000801042
Radioactive waste	3.9744	Radioactive Waste	1	3.9744
Slagg och aska	9.69546666666669	Slag and Ashes	1	9.69546666666669

Appendix 6. Environmental effect data for refinery and combustion of crude oil (Ltot*), calculated by EcoEffect;

name2	amount	weighting.name	effectFactor	Uttryck1
Ammoniak	0.000024759	Acidification	1.88	0.00004654692
Fluorsyra	0.0000855886	Acidification	1.6	0.00013694176
Nitrogen oxides	279.638328026023	Acidification	0.7	195.746829618216
Saltsyra	0.0000005994	Acidification	0.88	0.000000527472
Sulfat	0.01427804	Acidification	1	0.01427804
Sulfid	0.0000064348	Acidification	1	0.0000064348
Svaveldioxid	131.266666666667	Acidification	1	131.266666666667
Svaveloxider	0.14494596	Acidification	1	0.14494596
Benzene	0.0000422106	Ecotoxicity	3.6	0.00015195816
Benzene	0.0000422106	Ecotoxicity	4	0.0001688424
Toluene	0.0000236978	Ecotoxicity	0.97	0.000022986866
Toluene	0.0000236978	Ecotoxicity	4	0.0000947912
Toluene	0.0000236978	Ecotoxicity	10	0.000236978
Carbon dioxide	161462.667530678	Global Warming	1	161462.667530678
Carbon monoxide	1.1132263156	Global Warming	2	2.2264526312
Halon 1301	0.00000091	Global Warming	5600	0.005096
Lustgas	0.0003038692	Global Warming	320	0.097238144
Metan	0.0277352792	Global Warming	25	0.69338198
Benzene	0.0000422106	Human toxicity	2.3	0.00009708438
Benzene	0.0000422106	Human toxicity	14	0.0005909484
Benzene	0.0000422106	Human toxicity	10000000	422.106
Carbon monoxide	1.1132263156	Human toxicity	830	923.977841948
Nitrogen oxides	279.638328026023	Human toxicity	8600	2404889.62102379
Silver	0.00081172	Human toxicity	5.3	0.004302116
Sulphur dioxide	2.53	Human toxicity	1300	3289
Toluene	0.0000236978	Human toxicity	0.001	0.0000000236978
Toluene	0.0000236978	Human toxicity	0.004	0.0000000947912
Toluene	0.0000236978	Human toxicity	2500	0.0592445
Ammoniak	0.000024759	Nutrient Enrichment	3.64	0.00009012276
Cyanid	0.0000009748	Nutrient Enrichment	2.38	0.000002320024
Lustgas	0.0003038692	Nutrient Enrichment	2.82	0.000856911144
Nitrat	0.0001884186	Nutrient Enrichment	1	0.0001884186
Nitrogen oxides	279.638328026023	Nutrient Enrichment	1.35	377.51174283513
Total N	0.0002175548	Nutrient Enrichment	4.43	0.000963767764
Total P	0.0001425562	Nutrient Enrichment	32.03	0.004566075086
Halon 1301	0.00000091	Ozone Depletion	12	0.00001092

Benzene	0.0000422106	Ozone Production	0.2	0.00000844212
Carbon monoxide	1.1132263156	Ozone Production	0.03	0.033396789468
Metan	0.0277352792	Ozone Production	0.007	0.0001941469544
Toluene	0.0000236978	Ozone Production	0.6	0.00001421868
Radioactive waste	0.4368	Radioactive Waste	1	0.4368

Appendix 7. Environmental effect data for Eco-fibre when it is reused, calculated by EcoEffect:

name2	amount	weighting.name	effectFactor	Uttryck1
Ammoniak	0.00064665	Acidification	1.88	0.001215702
Fluorsyra	0.0022513	Acidification	1.6	0.00360208
Nitrogen oxides	52.3568196944445	Acidification	0.7	36.6497737861111
Sulfat	0.36404	Acidification	1	0.36404
Sulfid	0.00016765	Acidification	1	0.00016765
Svaveldioxid	11.8533333333333	Acidification	1	11.8533333333333
Svaveloxider	3.80805	Acidification	1	3.80805
Benzene	0.0010059	Ecotoxicity	3.6	0.00362124
Benzene	0.0010059	Ecotoxicity	4	0.0040236
Toluene	0.0006227	Ecotoxicity	0.97	0.000604019
Toluene	0.0006227	Ecotoxicity	4	0.0024908
Toluene	0.0006227	Ecotoxicity	10	0.006227
Carbon dioxide	14921.5844601556	Global Warming	1	14921.5844601556
Carbon monoxide	6.90768455	Global Warming	2	13.8153691
Halon 1301	0.00002395	Global Warming	5600	0.13412
Lustgas	0.0078556	Global Warming	320	2.513792
Metan	0.6852095	Global Warming	25	17.1302375
Benzene	0.0010059	Human toxicity	2.3	0.00231357
Benzene	0.0010059	Human toxicity	14	0.0140826
Benzene	0.0010059	Human toxicity	10000000	10059
Carbon monoxide	6.90768455	Human toxicity	830	5733.3781765
Nitrogen oxides	52.3568196944445	Human toxicity	8600	450268.649372222
Silver	0.0213634	Human toxicity	5.3	0.11322602
Sulphur dioxide	1.475	Human toxicity	1300	1917.5
Toluene	0.0006227	Human toxicity	0.001	0.0000006227
Toluene	0.0006227	Human toxicity	0.004	0.0000024908
Toluene	0.0006227	Human toxicity	2500	1.55675
Ammoniak	0.00064665	Nutrient Enrichment	3.64	0.002353806
Cyanid	0.00002395	Nutrient Enrichment	2.38	0.000057001
Lustgas	0.0078556	Nutrient Enrichment	2.82	0.022152792
Nitrat	0.00495765	Nutrient Enrichment	1	0.00495765
Nitrogen oxides	52.3568196944445	Nutrient Enrichment	1.35	70.6817065875
Total N	0.00572405	Nutrient Enrichment	4.43	0.0253575415
Total P	0.00361645	Nutrient Enrichment	32.03	0.1158348935
Halon 1301	0.00002395	Ozone Depletion	12	0.0002874
Benzene	0.0010059	Ozone Production	0.2	0.00020118
Carbon monoxide	6.90768455	Ozone Production	0.03	0.2072305365

Metan	0.6852095	Ozone Production	0.007	0.0047964665
Toluene	0.0006227	Ozone Production	0.6	0.00037362
Radioactive waste	11.496	Radioactive Waste	1	11.496

Appendix 8. Environmental effect data for Eco-fibre when it is put on landfill, calculated by EcoEffect:

name2	amount	weighting.name	effectFactor	Uttryck1
Ammoniak	0.00129357	Acidification	1.88	0.0024319116
Fluorsyra	0.00450354	Acidification	1.6	0.007205664
Nitrogen oxides	27.7179092277778	Acidification	0.7	19.4025364594445
Sulfat	0.728232	Acidification	1	0.728232
Sulfid	0.00033537	Acidification	1	0.00033537
Svaveldioxid	9.07333333333334	Acidification	1	9.07333333333334
Svaveloxider	7.61769	Acidification	1	7.61769
Benzene	0.00201222	Ecotoxicity	3.6	0.007243992
Benzene	0.00201222	Ecotoxicity	4	0.00804888
Toluene	0.00124566	Ecotoxicity	0.97	0.0012082902
Toluene	0.00124566	Ecotoxicity	4	0.00498264
Toluene	0.00124566	Ecotoxicity	10	0.0124566
Carbon dioxide	12074.6576009022	Global Warming	1	12074.6576009022
Carbon monoxide	3.58573139	Global Warming	2	7.17146278
Halon 1301	0.00004791	Global Warming	5600	0.268296
Lustgas	0.01571448	Global Warming	320	5.0286336
Metan	1.3707051	Global Warming	25	34.2676275
Benzene	0.00201222	Human toxicity	2.3	0.004628106
Benzene	0.00201222	Human toxicity	14	0.02817108
Benzene	0.00201222	Human toxicity	10000000	20122.2
Carbon monoxide	3.58573139	Human toxicity	830	2976.1570537
Nitrogen oxides	27.7179092277778	Human toxicity	8600	238374.019358889
Silver	0.04273572	Human toxicity	5.3	0.226499316
Sulphur dioxide	0.13	Human toxicity	1300	169
Toluene	0.00124566	Human toxicity	0.001	0.00000124566
Toluene	0.00124566	Human toxicity	0.004	0.00000498264
Toluene	0.00124566	Human toxicity	2500	3.11415
Ammoniak	0.00129357	Nutrient Enrichment	3.64	0.0047085948
Cyanid	0.00004791	Nutrient Enrichment	2.38	0.0001140258
Lustgas	0.01571448	Nutrient Enrichment	2.82	0.0443148336
Nitrat	0.00991737	Nutrient Enrichment	1	0.00991737
Nitrogen oxides	27.7179092277778	Nutrient Enrichment	1.35	37.4191774575
Total N	0.01145049	Nutrient Enrichment	4.43	0.0507256707
Total P	0.00723441	Nutrient Enrichment	32.03	0.2317181523
Halon 1301	0.00004791	Ozone Depletion	12	0.00057492
Benzene	0.00201222	Ozone Production	0.2	0.000402444

Carbon monoxide	3.58573139	Ozone Production	0.03	0.1075719417
Metan	1.3707051	Ozone Production	0.007	0.0095949357
Toluene	0.00124566	Ozone Production	0.6	0.000747396
Radioactive waste	22.9968	Radioactive Waste	1	22.9968

Appendix 9. Environmental effect data for Termoträ when it is reused, calculated by EcoEffect:

name2	amount	weighting.name	effectFactor	Uttryck1
Ammoniak	0.00008559	Acidification	1.88	0.0001609092
Fluorsyra	0.00029798	Acidification	1.6	0.000476768
Nitrogen oxides	69.001872261111	Acidification	0.7	48.3013105827777
Sulfat	0.048184	Acidification	1	0.048184
Sulfid	0.00002219	Acidification	1	0.00002219
Svaveldioxid	26.3933333333333	Acidification	1	26.3933333333333
Svaveloxider	0.50403	Acidification	1	0.50403
Benzene	0.00013314	Ecotoxicity	3.6	0.000479304
Benzene	0.00013314	Ecotoxicity	4	0.00053256
Toluene	0.00008242	Ecotoxicity	0.97	0.0000799474
Toluene	0.00008242	Ecotoxicity	4	0.00032968
Toluene	0.00008242	Ecotoxicity	10	0.0008242
Carbon dioxide	32258.4584140488	Global Warming	1	32258.4584140488
Carbon monoxide	4.39484593	Global Warming	2	8.78969186
Halon 1301	0.00000317	Global Warming	5600	0.017752
Lustgas	0.00103976	Global Warming	320	0.3327232
Metan	0.0906937	Global Warming	25	2.2673425
Benzene	0.00013314	Human toxicity	2.3	0.000306222
Benzene	0.00013314	Human toxicity	14	0.00186396
Benzene	0.00013314	Human toxicity	10000000	1331.4
Carbon monoxide	4.39484593	Human toxicity	830	3647.7221219
Nitrogen oxides	69.001872261111	Human toxicity	8600	593416.101445555
Silver	0.00282764	Human toxicity	5.3	0.014986492
Sulphur dioxide	4.061	Human toxicity	1300	5279.3
Toluene	0.00008242	Human toxicity	0.001	0.00000008242
Toluene	0.00008242	Human toxicity	0.004	0.00000032968
Toluene	0.00008242	Human toxicity	2500	0.20605
Ammoniak	0.00008559	Nutrient Enrichment	3.64	0.0003115476
Cyanid	0.00000317	Nutrient Enrichment	2.38	0.0000075446
Lustgas	0.00103976	Nutrient Enrichment	2.82	0.0029321232
Nitrat	0.00065619	Nutrient Enrichment	1	0.00065619
Nitrogen oxides	69.001872261111	Nutrient Enrichment	1.35	93.1525275524999
Total N	0.00075763	Nutrient Enrichment	4.43	0.0033563009
Total P	0.00047867	Nutrient Enrichment	32.03	0.0153318001
Halon 1301	0.00000317	Ozone Depletion	12	0.00003804
Benzene	0.00013314	Ozone Production	0.2	0.000026628
Carbon monoxide	4.39484593	Ozone Production	0.03	0.1318453779

Metan	0.0906937	Ozone Production	0.007	0.0006348559
Toluene	0.00008242	Ozone Production	0.6	0.000049452
Radioactive waste	1.5216	Radioactive Waste	1	1.5216