ENVIRONMENTAL SYSTEMS ANALYSIS TOOLS

-differences and similarities

including a brief case study on heat production using

Ecological footprint, MIPS, LCA and exergy analysis

by

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ABSTRACT

Several concepts and tools for achieving a more sustainable future have been developed. They are developed within separate disciplines and for somewhat different purposes. This study is divided into two parts. The first contains a brief description of eleven environmental systems analysis tools, outlining background, shortly describing the performance of the method and answering a set of questions regarding context and methodology. The tools described include environmental impact assessment (EIA), strategic environmental assessment (SEA), life cycle assessment (LCA), positional analysis (PA), cost-benefit analysis (CBA), material intensity per unit service (MIPS) analysis, total material requirement (TMR) analysis, ecological footprint (EF), exergy analysis, emergy analysis and risk assessment (RA) for chemicals.

In the second part four of the tools are applied on a case study where different fuels for district heat production are analysed. The purpose of this case study is not to present the preferable fuel for heat generation, but rather to illuminate problems and characteristics of the tools used. Four fuels are analysed Salix, forest residues, household waste and fossilgas and the tools used are LCA, MIPS, EF and exergy analysis. The results show upon similarities between MIPS and exergy analysis and also to some extent with LCA. The footprint on the other hand provided other relations between the total fuel impacts. Besides discussing the results and experiences from the performance of the analyses, an overall comparisons between the eleven tools previously described are made.

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1. INTRODUCTION

Recently environmental questions have started to climb on the agendas of authorities and companies as well as of individuals. The awareness of the international character and the complexity of environmental problems and the needed mitigation efforts has risen. Stakeholders in various situations want more information in this field. This has lead to an increased need for tools to promote learning and give decision-support, providing knowledge that will hopefully give environmental discussions more weight and focus. It is easy to point out that actions need to be taken, still, constructive advice regarding where such actions would be most efficient and most needed to start changes would be more helpful.

Ideas and methods supporting better environmental management have arisen within several disciplines. Some of these approaches can more be considered as concepts i.e. ideas of how to reach sustainability. Tools, on the other hand, are often supporting a concept and presenting a more systematic way of measuring environmental burden, indicating progress towards sustainability, etc. The defining borders between concepts and tools are a bit vague with over-lapping and inclusions occuring. Ecospace, Design for the Environment, Industrial Ecology, Dematerialisation and Eco-Efficiency are examples of concepts. Industrial Ecology and Dematerialisation can be considered as sub-concepts to Eco-Efficiency, since both are based on this same thought only applying it in differing ways (*OECD, 1995)*. Some approaches may be considered as both being a concept and a tool (e.g. ecological footprint, exergy concept/analysis).

Several environmental systems analysis tools have become available for companies, governments, authorities and others. Environmental systems analysis tools, as defined in this study, are facilitating the assessment of environmental impacts and/or natural resource use caused by the system studied through some sort of analysis. The system studied may be a product, a service, an economy or a project, Many tools are under continuos development and are still more or less unstandardised, sometimes making it hard to keep up with the latest methodology. It can also be hard to separate all analyses and assessments from each other. Similar names are used, or similar methods are developed under separate names. Baumann and Cowell *(1998)* conclude that there is some concern that the development of, and efforts to operationalise concepts and tools are being done in parallel in different disciplines, resulting in inefficient improvement processes.

Several compilations of environmental management/assessment methods have been published *(e.g. OECD, 1995, Baumann and Cowell, 1998, Jönsson, 1998, Bolund et al., 1998, SETAC, 1997)*, where methods are characterised and sometimes compared. There are also studies comparing only two, three methods *(e.g. Tillman et al. 1997, Bjuggren, 1998)*. More comparative studies with practical guidance are needed and also broader compilations. It is important to overcome the “borders” between different disciplines.

Another compilation is under progress within CHAINET (European Network on Chain Analyses for Environmental Decision Support), which is a project under the EU Environment and Climate Programme. The project will lead to a guidebook on usability of tools, mainly concerning production/consumption. It is expected to be finished in December 1999. *(CHAINET, 1998)*

1.1 The aim of the study

The aim of this study is to shortly describe and compare eleven of the manifold environmental systems analysis tools to visualise differences and similarities, weaknesses and strengths. This is done to the greater part from a Swedish perspective. The study will hopefully facilitate choice of tools as well as critical interpretation of results. The study is not at all aiming to create a complete list, a more thorough study will have to be made to present a more comprehensive list of environmental systems analysis tools. A brief case study on four fuels (Salix, forest residues, household waste and fossilgas) for district heating will also be made using selected relevant tools. Results from this case study will be used in discussing the characteristics of the tools.

2. DESCRIPTION OF THE TOOLS

In this first part of the study eleven environmental tools are presented (see list below). A short description of their background is given, methodological steps and also in some cases on-going or needed development. Fourteen questions are used to describe the tools in the same manner to facilitate comparison. This first part is a guide to the tools and similarities and differences between them will be discussed later.

2.1 Selecting questions and tools

2.1.1 Why these tools?

There are a lot of interesting methods. The selection of methods to be included in this study can be considered subjective but also based on the current use of methods. Some methods are considered as more commonly used (EIA, LCA), and are thereby included and a mix of energy- and material-focused analysis is wanted (MIPS, TMR, exergy, emergy). A couple of tools including social and economic aspects as well as environmental are added (CBA, PA). SEA, as a rather new, strategic tool seems interesting and the ecological footprint is selected because of its unique way of converting environmental impacts to land and water area. Risk assessment for chemicals was planned to be accompanied by the same assessment for accidents, but the limits of time prevented this. The selection results in a mixture of tools specified on products, services, projects and economies; focusing on different environmental impacts; and with varying scope of analysis. This is in no way presented as a list of tools more relevant than others, but rather as a selection of some, from my perspective, interesting methods incorporating some of the most commonly used.

- Environmental Impact Assessment (EIA)
- Strategic Environmental Assessment (SEA)
- Life Cycle Assessment (LCA)
- Positional Analysis (PA)
- Cost-Benefit Analysis (CBA)
- Material Intensity Per Unit Service (MIPS)
- Total Material Requirement (TMR)
- Ecological Footprint (EF)
- Exergy Analysis
- Emergy Analysis
- Risk Assessment (RA), for chemicals

From the beginning, risk assessment for major accidents (as mentioned above), environmental auditing and impact pathway analysis were on the list as well, but time proved insufficient to implement this wish.

2.1.1 Key to the questions

The Working Group on Conceptually Related Programmes, set up by SETAC (the Society of Environmental Toxicology and Chemistry), has presented a framework for describing relationships between LCA and other environmental management concepts and tools *(SETAC, 1997)*. This framework has been developed by Baumann and Cowell *(1998)*. In this paper, questions for description of the tools are based on aspects considered in the framework used in these two publications. LCA is the working field of the writers of both these publications and terminology and aspects may thereby in parts be LCA-oriented.

The questions have been adapted for this study and are formulated with the intention to help in giving a picture of the scope of the tool as well as the potential situations where it can be used. All the described methods are assumed to be of analytical nature and to be tools rather than concepts. The questions used are presented below, with some explanations.

- **Overall purpose of using the tool?**

The overall purpose describes the main reason for the development of the tool. This can be described as communication or decision-support. The aim of the former is to provide others with information, while the latter will advice the user in operative or strategic decision situations *(Baumann and Cowell, 1998)*. In some cases the purpose may also be more of learning nature, not directly supporting decisions.

- **Which object is being analysed?**

This question specifies which object is being analysed, e.g. a product, a function or an economy.

- **What is the reason for performing the analysis for the different users?**

The different user categories can be described as companies, governments/authorities, and NGOs *(SETAC, 1997)*. Their reasons for using the method can vary from choice of location of a planned facility (EIA) to wanting to underline the preferability of a certain product/service/lifestyle (LCA, EF, MIPS, exergy, etc.).

- **In what perspective may the analysis be used?**

Tools may be snapshots in time, they may consider the whole time frame wherein a product or project has an impact. The result of the analysis may then be used in retro- or prospective ways. The former is accounting/monitoring, keeping record of progress, which can be useful when searching for preferable changes in for example production, behaviour or policies and to indicate sustainable development. Prospective approaches, on the other hand, are seeking to predict future situations and can thereby facilitate comparison between different new products, plans, etc. *(SETAC, 1997)*.

- **Which are the system boundaries?**

Regarding the temporal boundaries, a method can either look at a snapshot in time, or several snapshots leading to a series conveying progress/change. Some tools look at a lifetime of a product or process or rather the lifetime of their impacts. Spatial boundaries can be the boundaries of a country or town, it can also be boundaries surrounding a section in a production chain and the boundary between nature and the human system.

- **Is there a need for a reference object?**

Some analyses lead to results sufficient on their own, while others need a reference to be compared with in order to be informational.

- **What is the unit of the result?**

Gives a hint about how the results are presented.

- **What kinds of effects are considered (environmental, economical and/or social)?**

Some approaches are strictly environmental, while some are aiming to get a wider picture incorporating economical and social aspects as well.

- **What environmental burdens are considered?**

In Table 1 (p 48) environmental burdens are listed, modified from the list of "13 environmental threats in Sweden" provided by the Swedish environmental protection agency. Resource use has been added as additional burdens.

- **Is the method quantitative or qualitative?**

Most of the methods are both quantitative and qualitative, but the emphasise is usually on either of them.

- **Do the performance of the analysis include follow up?**

A final part of the analysis may be to account for progress (or the lack of progress). This is useful for the issue under study, but also for development of the tool.

- **Is the method standardised/harmonised?**

This question is relevant, even if many methods are under continuos development. If different users apply the tool in separate ways, evolution will make it harder to keep the tool homogenous in the future. General guidelines can be subsequently added to as development brings new /better advice to achieve continuos harmonisation.

- **Where and how frequently is it being used?**

Under this heading some information is presented about whether the analysis is often practised and sometimes also where, geographically, it is used.

- **Strengths and weaknesses of the method.**

Under this heading positive and negative opinions commonly expressed are presented without any personal standpoints and opinions of the correctness of these.

2.2 Environmental Impact Assessment (EIA)

Based on:
- Baumann K. and Cowell S., 1998.
- Balfors B., 1997.
- Glasson J., Thérivel R. and Chadwick A., 1999.
- Regeringens proposition 1997/98:45.
- RRV, Riksrevisionsverket, 1996.
- SEPA, Swedish Environmental Protection Agency, 1996.
- Thérivel R. et al., 1992.
- Tillman A-M. et al., 1997.

2.2.1 Background

The establishment of Environmental Impact Assessment, EIA, began with the 1969 US National Environmental Policy Act (NEPA). Rapidly following were countries like Canada, Australia, West Germany and France. An EC Directive (85/337) aimed to level requirements of EIA within member states, since this directive did not have much effect amendments were made in 1997*(Glasson et al., 1999)*. This is the only environmental analysis tool required by law for some situations in Sweden.

In Sweden discussions concerning EIA (miljökonsekvensbeskrivning, MKB) started in the 70s, but these discussion resulted merely in requirements to include a description of potential environmental impacts in the permission application according to the Environmental Protection Act. In practice this lead to no relevant changes. EIA was made compulsory, as it was included in the Road Act (1971:948) in 1987*(RRV, 1996)*. In 1988 the Parliament decided, against the opinion of the Government, to introduce EIA in Sweden. Finally, in 1991, an EIA-requirement was incorporated into the law of natural resources (NRL) *(RRV, 1996)*. In the government bill for the new environmental legislation minimum requirements for what to include in an EIA document are stated *(Prop. 1997/98:45)*.. The need for performances of EIAs will increase with this new legislation, since laws where EIAs were not mentioned earlier will now be covered by the EIA demand. Influence of public opinion is to be increased and considered at an early stage.

EIA has been defined broadly as an investigation of impacts on environment and human well-being resulting from policies and legislative proposals and more narrow as a means of assessing environmental effects of a project. The United Nations Economic Commission for Europe has a short and easy definition: “an assessment of a planned activity on the environment” *(Glasson et al., 1999)*.

The terminology around EIA can be confusing. The Swedish term MKB has double meanings and describes both the process and the document that the process leads to. In the USA the document is called an Environmental Impact Statement (EIS), if a less thorough assessment is made the document is called an Environmental Assessment (EA). To further complicate things, EA is in Great Britain the definition of the process and the document is called an Environmental Statement (ES) *(Tillman et al., 1997)*.

As stated in the Swedish Environmental Protection Agency’s report 4666 *(1996)*, ”the applicant should begin EIA work as early as possible”. Preferably considering environmental aspects alongside economical and technical ditto already at the idea stage. Riksrevisionsverket *(1996)* claims that this is often not the common case.

2.2.3 How to perform an EIA

The process of an EIA may vary substantially, in figure 1 important steps of the process are illustrated.

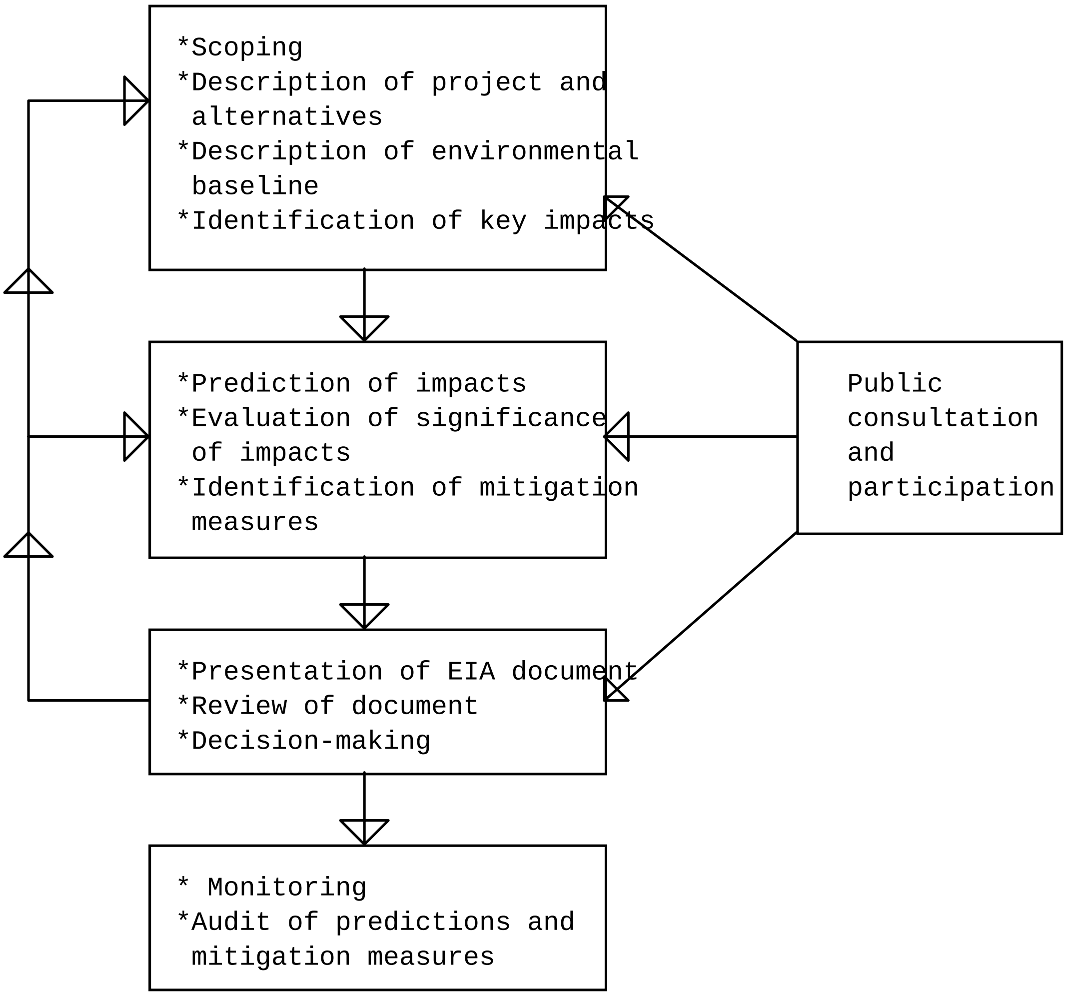


Figure 1. Important steps in the EIA process, which is an iterative process *(from Glasson et al., 1999)*.

Producing an EIA document

In the governmental bill *(Prop. 1997/98:45)* five stages to be included in an EIA document are described (primarily for development with considerable environmental impact).

1. Description of the development (location, design and extent)
2. Description of mitigation measures
3. Information making possible the estimate of major impacts on health, environment and resource management
4. Presentation of alternative locations (if possible) and alternative designs, including the zero-alternative. Motivating the choice of alternative
5. Non-technical summary of 1-4

2.2.3 Description

Overall purpose of using the tool?

This tool is developed to get environmental aspects into project planning. Strategic decision-support is the purpose of using it.

Which object is being analysed?
Mainly proposed projects (industry facilities, road constructions, etc).

What is the reason for performing the analysis for the different users?
Support government and other authorities in decisions concerning permits for proposed projects. Support authorities in town planning and comprehensive municipal planning. *(Tillman et al., 1997)*

In what perspective may the analysis be used?
Prospective, foresees impacts of planned activities.

Which are the system boundaries?
Wood (1995) states that, in principle, the boundaries are defined by the distribution (spatial and temporal) of important direct and indirect impacts caused by the proposed project *(Baumann and Cowell, 1998).*

Is there a need for a reference object?
There is no obvious need for a reference object, since the EIA tells what effect a planned action will have on an area. However, there is a requirement that EIA should consider alternatives to the proposed project localisation (exceptions can be made) and design, including the zero alternative describing what will happen if the project is not carried out *(NV, 1996)*. This means, a comparison is required.

What is the unit of the result?
Several different units.

What kinds of effects are considered?
In Sweden environmental, including human health, are the only effects considered, social effects are according to Glasson et al. *(1999)* included in EIAs in some countries and in other handled as a separate process, Social Impact Assessment (SIA).

What environmental burdens are considered?
In the governmental bill for the new environmental legislation it is stated that the purpose of an EIA is to identify and describe the direct and indirect impacts of the development on humans, animals, vegetation, ground, water, air, climate, landscape and cultural environment, as well as resource management *(Prop. 1997/98:45)*. As can be seen in table 1, this would in theory mean that all environmental burdens should be considered. In practice, this is probably not be the case.

Is the method quantitative or qualitative?
Both qualitative and quantitative.

Do the performance of the analysis include follow up?
Yes, monitoring and control is part of the suggested performance *(RRV, 1996).*

Is the method standardised/harmonised?
There is an international agreement on general procedure *(Tillman et al., 1997)*. For Swedish performance, there are guidelines and also some legal requirements.

Where and how frequently is it being used?
This is one of the more frequently used environmental systems analysis tools. EIAs are performed in several countries including some developing countries *(Balfors, 1997).*

Strengths and weaknesses of the method
+
- Gives the decision-makers environmental aspects of the project proposed.
- The public supposedly makes its voice heard.
- Well-known and often performed.
- Legally required.

-
- Thorough EIAs are expensive (Thérivel et al., 1992).
- Lack of testing against what really happens (even though monitoring is part of the suggested performance). This limits the potential for improvements of the method (Bisset and Tomlinson, 1988 and Coles et al., 1992 in Thérivel et al., 1992).
- Adversely interested are contacted too late (RRV, 1996).
- EIA-performers often rely on too weak data from regional authorities (RRV, 1996).
- According to Riksrevisionsverket (1996) large problems in the Swedish procedure include subjectiveness (the EIA is considered a statement from one side), small possibilities to correct bad EIA's, and the EIA's play a small role in the decision-making process.

2.3 Strategic Environmental Assessment (SEA)

Based on:
- Balfors B., 1997.
- Glasson J., et al. 1999.
- TemaNord, 1996.
- Thérivel R. et al., 1992.
- Thérivel R. and Partdário M.R., 1996.
- European Commissions, 1996.

2.3.1 Background

Strategic environmental assessment (SEA) can be seen as an improvement of and a complement to the EIA, which is mainly performed on project level. As it often proved unsatisfactory to achieve changes in basic questions leading to considerable environmental improvements at the stage where EIA is applied, there was a need for a tool usable earlier in the decision-making process. To use the project-EIA method on a strategic level analysing plans, programmes and policies turned out inappropriate since differences are too great concerning content, concreteness and decision process between the project and the more strategic level. Development of a new method became necessary. *(Tema Nord, 1996:538)*

SEA is the environmental assessment of a strategic action, and strategic actions are defined as policies, plans and programmes (PPP). Other, less common international descriptions of this kind of method are policy environmental assessment, sectoral environmental assessment, programmatic environmental assessment, etc. (the Swedish word is ”strategisk miljöbedömning”) *(Balfors, 1997)*. Current international use of SEA is described by Glasson et al. *(1999)*. USA, the Netherlands and New Zealand all have established this tool in their legislation. However, it turns out they use and interpret the method in various ways. In USA SEA is defined as a tool for impact minimisation and may thereby be considered as a development of project-EIA. In New Zealand the focus is more on sustainable development and integration of this concept in all PPPs, formal SEAs are seldom performed. The Netherlands, finally, use a two-fold approach. They set up quantitative goals to achieve carrying capacity and start actions to reach these goals, including integration of sustainability aspects into policy assessments. These different applications presented by Glasson et al. *(1999)* illuminate some lack of harmonisation of this new tool.

In the government bill for new environmental legislation there is an invitation for regional authorities (Länsstyrelserna) to demand SEAs for strategic actions that are considered to result in large environmental impacts *(Prop. 1997/98:45)*. If this ends up in formal regulations will be revealed in 1999. To develop the method pilot cases have been performed in Sweden. The cases concern Stockholm's future water supply and a proposal for future politics of traffic *(Balfors, 1997)*. There is no general methodology recommended *(B. Balfors, Kungliga Tekniska Högskolan, personal communication)*. A proposal for an EC council directive on SEA (COM/96/0511 final) was presented by the Commission in December 1996 *(European Commission, 1996)* the scope is however rather narrow only including recommendations for some plans and programmes. According to Glasson et al. *(1999)* a soon adoption of the directive is nevertheless unlikely.

SEA on PPPs are performed at varying detail, policies are often much more vague in their presentation and may cover broad areas (geographical and social) whereas some programme SEAs may be performed at almost the same details as project EIAs *(Thérivel and Partdário, 1996)*. PPPs are tiered (including each other), making SEAs on programmes subordinated earlier SEAs on the relevant plan/s and also policy/ies.

2.3.2 How to perform an SEA

Riki Thérivel *(Thérivel and Partidário, 1996)* has reviewed good practice methodology and described the current ”best practice” of an integrated SEA as follows. SEA is an iterative process. All stages presented are not relevant for all SEAs.

The performance of SEA as described by Thérivel and Partidário *(1996)* is described below, see also Figure 2.

- **Setting objectives and targets of PPP.** States the purpose of the PPP. Primary objectives may be stated vaguely and therefore more specific objectives underlying the broader and more vague or even un-stated objective should be presented as well.
- **Identifying alternative PPPs**. A zero-alternative may be included.
- **Describing the PPP**. The future PPPs appearance is described and this is considered as the most difficult step, more difficult the higher-level the PPP. Time span is also estimated.
- **Scoping**. Selection of the crucial environmental aspects that will be included in the assessment and explaining why others are left out. Geographically relevant area should also be stated.
- **Establishing environmental indicators**. Indicators should represent key issues and interests, be based on easily available data, lead to transparent results, etc. They are generally state-of-the-environment indicators (e.g. NOx levels), impact/pressure indicators (eg. NOx emissions) and/or action indicators (e.g. percent of cars with catalytic converters). The indicators will be used to describe zero-action conditions and potential impacts for different alternatives and later also to monitor implementation.

- **Describing the baseline environment**. Describing the current and zero-action environmental state to make comparison with the different development alternatives possible.
- **Predicting impacts**. Determining the potential impacts (type and magnitude) of the PPP on the baseline environment (direct, indirect and cumulative).
- **Evaluating impacts and comparing alternatives**. The predicted impacts are evaluated according to significance and tested for relevance according to PPP objectives. Significance is determined as magnitude/type of impact combined with sensitivity and importance of receiving environment with evaluation based on expert judgement.
- **Mitigation**. Mitigation measures are measures that avoid, repair or compensate for impacts. After including mitigation measures re-evaluations have to be made to estimate remaining negative impacts. This process will go on until no significant negative impacts are predicted.
- **Monitoring**. This step is important from many angles; investigation of objectives and targets achievement of the PPP; ensuring that decided mitigation steps are taken; identifying negative impacts not covered by the mitigation efforts; giving feedback to enhance future studies.

Since SEA is evaluating dynamic processes the assessments need to be continuously updated *(Tema Nord, 1996).*

2.3.3 Description

Overall purpose of using the tool?
Decision-support at a strategic level, but also function as a tool for integrating sustainability into planning and assessment processes *(Glasson et al., 1999)*. This tool is used at an earlier level than project EIA.

Which object is being analysed?
Policies, plans and programmes.

What is the reason for performing the analysis for the different users?
Supporting government and other authorities preparing or modifying policies, plans or programmes. One of the benefits of SEA is the early entry. Decision-makers get important environmental ingredients before too much has been settled.

In what perspective may the analysis be used?
Prospective, predicting future effects.

Which are the system boundaries?
Boundaries are defined for each specific PPP, depending on its time-span and geographical influence area.

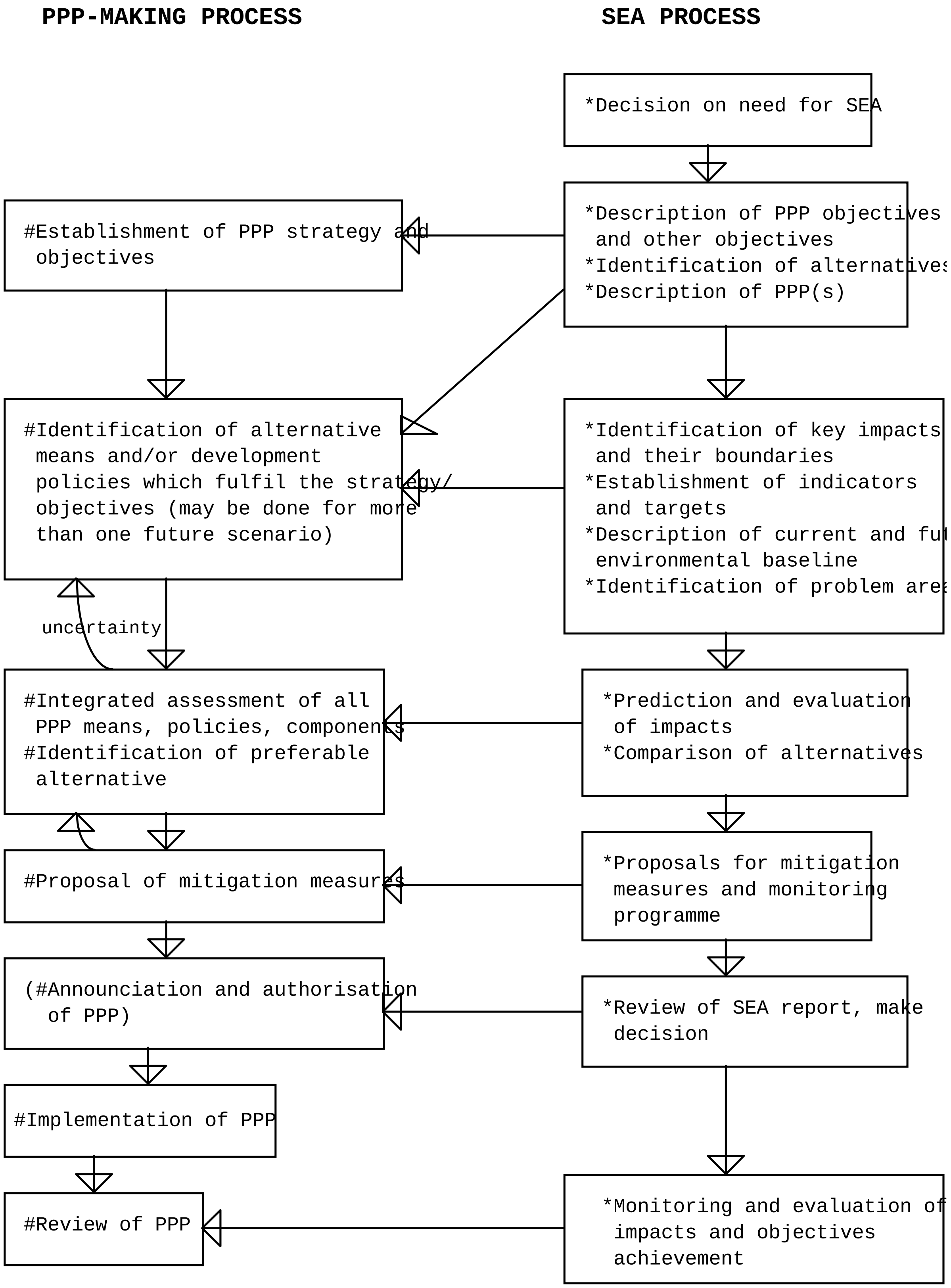


Figure 2. Steps of and links between PPP-making and SEA *(from Thérivel and Partidário, 1996).*

Is there a need for a reference object?
Comparison is made between alternatives described within the SEA, when relevant including zero-alternative.

What is the unit of the result?
Several different units.

What kinds of effects are considered?
Environmental.

What environmental burdens are considered?
Theoretically all but as stated in the EIA description some impacts are hard to estimate in practice (Tab. 1).

Is the method quantitative or qualitative?
Both qualitative and quantitative.

Is the method standardised/harmonised?
No, methodology and examples of practices are presented in e.g. Thérivel and Partidário *(1996)*.

Where and how frequently is it being used?
SEA is a rather new tool, applied only in some fields in a few countries. SEA legislation has been established in USA, the Netherlands, New Zealand and Western Australia. Some requirements are also decided on in Canada, Denmark and Hong Kong. Generally regulations are restricted to plan and programmes, not including policies *(Glasson et al., 1999)*.

Strengths and weaknesses of the method
+

- Makes it possible to investigate alternatives early in the decision-making process, which also gives experts more time to collect relevant data *(Thérivel et al., 1992)*.
- Helping to put principles of sustainability into operation *(Thérivel et al., 1992)*.
- Giving an opportunity for public involvement in policy formulation *(Thérivel et al., 1992)*.
- Ensuring systematic appraisal of choices *(Thérivel et al., 1992)*.
- Possible to see cumulative effects (but maybe hard).
- Makes consideration of more diverse alternatives possible, than when using EIA.
- Facilitates more continuos communication between different actors *(Balfors, 1997)*.

-

- Proposals for plans and policies are often diffuse, and decisions are often made in an incremental and not clearly formulated way which may make the performance of SEAs hard *(Thérivel et al., 1992)*.
- Problems with system boundaries may occur. Many potential decisions flow from a higher-level decision, which leads to analytical complexity. *(Thérivel et al., 1992)*
- A large number and variety of alternatives have to be considered at the different stages of policy formulation *(Thérivel et al., 1992)*.
- There is a high uncertainty in trying to tell the future, especially concerning effects of policies. This is worsened by the limited accessibility of information at early strategic levels *(Glasson et al., 1999)*.

- There are few models for performance of SEA, because there are few reports of successful SEAs *(Glasson et al., 1999).*
- The high diversity in situations where SEA is needed makes standardisation of guidelines difficult *(Balfors, 1997).*
- Using the SEA as a way of integrating sustainability aspects in PPPs may have a disadvantage by being a very long term approach and also because sustainable development parameters may be hard to set as well as carrying capacity levels, since many outside factors will contribute *(Glasson et al., 1999).*

2.3.4 Development

In Tema Nord 1996:538 it is stated that, even if the development need is big, the practical performance of SEA is restricted more by lack of political and institutional will and appropriate structure, than by lack of methods and concepts. It is important to have the courage to use this tool to facilitate its development and also to start early inclusion of sustainability aspects in decision processes. Still, there is a big need for methodology development and guidelines *(Balfors, 1997).*

2.4 Life Cycle Assessment (LCA)

Based on:

- Anderberg S. et al., 1997.
- Finnveden G., 1998.
- Finnveden G., 1999.
- ISO, 1997.
- Lindfors L.G. et al., 1995.
- Lohm U., 1997.
- Naturvårdsverket, 1996.
- Tillman, A-M., et al., 1997.
- UNEP Industry and Environment, 1996.

2.4.1 Background

Following the energy crisis of the 1970s methods for analysing energy requirements in production processes were developed. LCA was developed in parallel and influenced by these energy focused approaches. LCA was extended to include depletion of resources (other than energy carriers) and also impacts of emissions and waste produced. *(UNEP, 1996)*

Early studies were made in USA, Sweden and the UK *(Tillman et al., 1997)*. In the 80s, as environmental questions were gaining more interest, interest in LCA increased as well. Some scepticism arose when assessments of one and the same product resulted in conflicting statements. The development of a common methodology started *(UNEP, 1996)*. The method, as defined today, is relatively new and still under development. Standardisation and harmonisation of the method is underway, by ISO (International Organisation for Standardization) since 1993 and SETAC (Society of Environmental Toxicology and Chemistry) since 1990.

LCA is in theory covering potential environmental impacts of a product/service during its entire lifetime, “from cradle to grave”. This includes extraction of raw material, energy use and waste release, as well as all associated transports. Obviously this is a rather tough assignment, which is often reduced to a more manageable study. It is of great importance that boundaries set around the system is transparently stated in the document produced. If some flows are not followed all the way to their origin or "grave" this must also be clearly stated. *(Lindfors et al., 1995)*

Focus of the assessment is not the product itself but rather the function of it. An important part of the LCA procedure is to define the functional unit under study. This unit can for example be a number of coffee cups/year and defines what is actually compared. *(UNEP, 1996)*

2.4.2 How to perform an LCA

"Views on the main methodological issues involved are now converging" *(UNEP, 1996)*

The LCA framework *(ISO, 1997 and UNEP, 1996)*: (Fig. 3)

1. **Goal definition and scope.** The purpose of the study and the target group are stated. Product/function to be analysed and level of detail and certainty required is defined. As the study progresses the goal definition may be revised and refined.
2. **Inventory analysis**
   - 2.1 Constructing the process flow chart. The process flow chart is a graphical overview of the processes included in the life cycle.
   - 2.2 Collecting the data.
   - 2.3 Defining the system boundaries. This definition is done using knowledge obtained in previous steps.
   - 2.4 Processing the data.
3. **Impact Assessment**
   - 3.1 Classification. Environmental problems to be included are defined and the data from the inventory analysis are grouped with relevant categories.
   - 3.2 Characterisation. Quantifying respective input/output's contribution to respective environmental problem by using equivalency factors (e.g. global warming potential).
   - 3.3 Valuation. The environmental problems are weighted against each other. Valuation can be based on established opinions (society, experts, public).
4. **Interpretation**. Findings from 2 and 3 are added together and conclusions are drawn recommendations may be made.

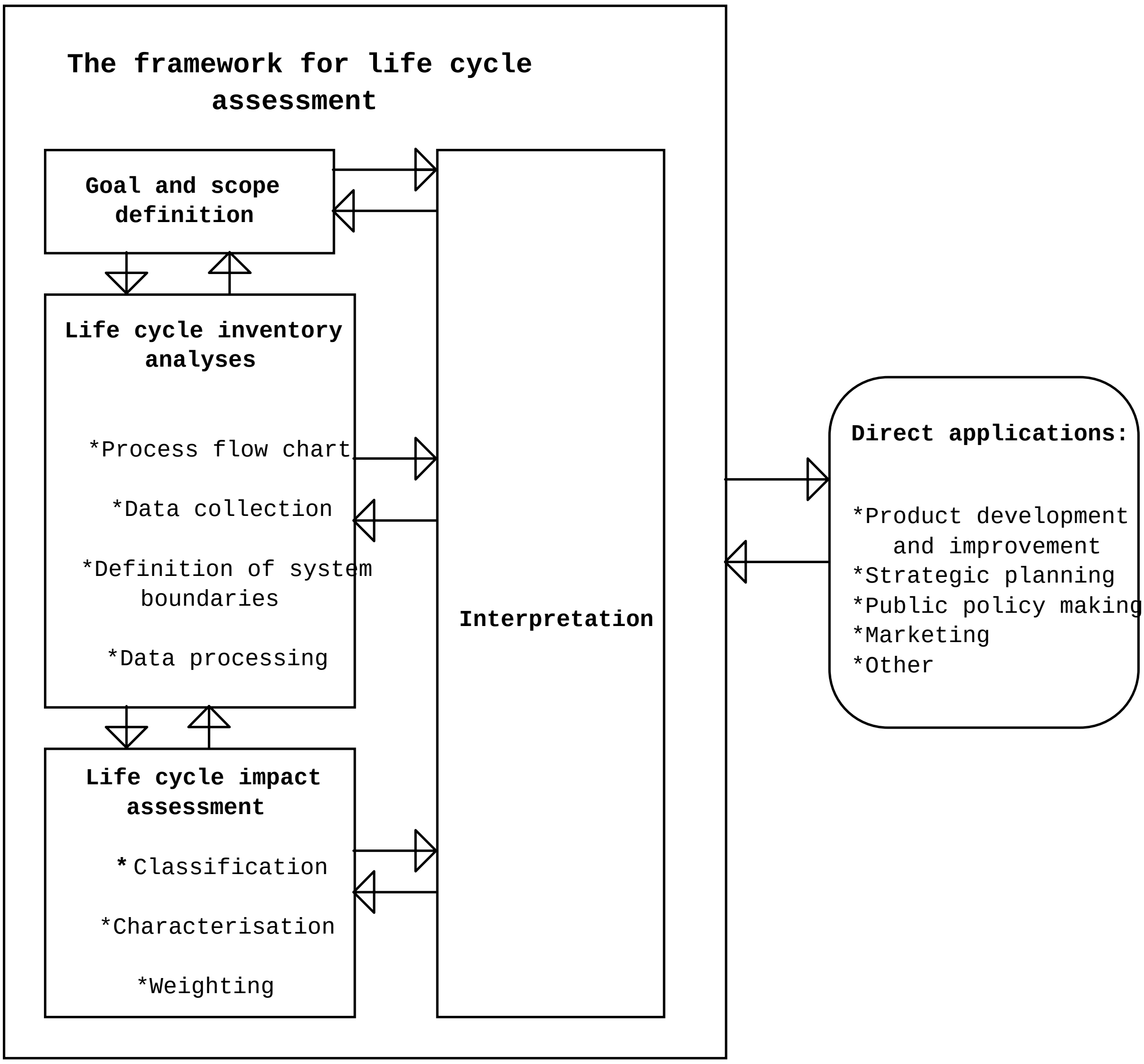


Figure 3. The steps of LCA, which is an iterative process *(modified from ISO, 1997).*

The first three steps are part of an iterative process. The impact assessment can be excluded and inventory data used directly, this is then called Life Cycle Inventory (LCI). When performing an LCA you may choose to stop either after the classification, characterisation or valuation. Using the ISO standard, the valuation step is not allowed for external studies *(ISO, 1997).*

Within the general framework, there is still room for a number of methodological choices because LCAs are performed in various ways making comparisons difficult. Choice of system boundaries as well as choice of characterisation and valuation methods will have big influence of the final result. It is important that it is clearly stated exactly how the assessment has been performed, to avoid incorrect comparisons. LCA is not intended to end in an environmental index resulting from the valuation. Interpretation is done considering all steps in the assessment and the final result is broader than the outcome of the valuation.

2.4.3 Description

Overall purpose of using the tool?
Currently, it is mainly used by companies for internal learning purposes. LCA may also serve both as a tool for communication and decision-support. As UNEP *(1996)* explains it ”the aim of LCA is to suggest more sustainable forms of production and consumption”.

Which object is being analysed?
Products and functions

What is the reason for performing the analysis for the different users?
- learning (companies)
- communications of environmental aspects of products (companies, authorities, NGOs)
- product and process improvement (companies)
- product and process design (companies)
- development of business strategies (companies)
- development of product policies (companies)
- development of policy strategies (authorities, companies, NGOs)
- purchasing decisions (authorities, companies, NGOs)
- setting ecolabelling criteria (authorities, NGOs)
- development of life styles (authorities, NGOs)

(UNEP, 1996)

In what perspective may the analysis be used?
LCA is taking the whole lifetime of a function in account using current knowledge of emissions, technology, etc. The analysis may be used prospectively when used for development of new products, strategies etc. and retrospectively when used to improve processes and products, for purchasing decisions, etc.

Which are the system boundaries?
According to UNEP *(1996)* there are three important boundaries to set:
- between the technical system and the environment
- between the system under study and other related systems
- between relevant and irrelevant processes

Since the assessment is not site- specific, there are no geographical boundaries. Performing an LCA, when and where resource depletion and emissions will be made is not known. Time considered is the whole lifecycle, this means that in theory the timeframe of the study should reach the time where no impacts related to the function under study could be found. Since emissions from deposits continue for many centuries a cut off time is most often used (e.g. 100, 500 years) *(Finnveden, 1998).*

Is there a need for a reference object?
Yes, either the same product/service produced in an alternative way, or another product/service producing the same ”result”. Comparison can also be made between parts of a system to identify parts where changes are most efficient.

What is the unit of the result?
Either you can choose to finalise the analysis before the valuation step, then several units are used in the result. If the valuation step is included there are several different valuation methods available presenting the valuation results in different units *(Lindfors et al., 1995).*

What kinds of effects are considered?
It is purely environmental effects that are considered.

What environmental burdens are considered?
All environmental impacts are, in theory, considered (Tab. 1). In practice, however noise in cities, introduction of foreign species, land requirements for infrastructure, biodiversity loss and over use of renewable resources are often only mentioned and defined as not included. The effects of waste are not yet sufficiently analysed but development in this field is ongoing.

Is the method quantitative or qualitative?
Quantitative, incorporating qualitative data when only these are available *(Lindfors et al. 1995).*

Do the performance of the analysis include follow-up?
No.

Is the method standardised/harmonised?
Yes, ISO standardisation is on going and earlier harmonisation has been performed by e.g. SETAC.

Where and how often is it being used?
LCA is one of the more frequently used environmental systems analysis tools and the knowledge of its performance is spreading. For example UNEP is promoting its implementation through its Cleaner Production Programme *(UNEP, 1996).*

Strengths and weaknesses of the method.
+

- LCA, at least in theory, covers all possible impacts on the environment of a product/function.
- Avoids problems shifting from one stage in the lifecycle to another, from one sort of environmental problem to another and from one location to another (exporting chemicals for example) *(UNEP, 1996).*
- Tries to account for toxicological impacts.
- It is acknowledged in many countries.
- Standardisation is underway.

-

- A problem shifting which can not be seen in the LCA is the shift to other products (ex. recycling of ashes from incinerators might spread heavy metals from different kinds of products burned)*(UNEP, 1996).*
- Time consuming, which may delay action.
- In practise not considering future changes (technical improvement, changes in demand), which may make the results very short-lived *(Anderberg et al., 1997).* Not constructed to see new solutions and developments *(Lohm, 1997).*

- Only known and measurable environmental impacts are considered *(Anderberg et al., 1997)*.
- Since LCAs do not take geographical aspects into account synergistic effects are not considered.
- Subjective to when it comes to deciding when further processes do not change the outcome of the analysis.
- Data problems (not even the companies can always give exact mass balances for processes) *(Lohm, 1997)*. It may also be hard to achieve good data when performing external studies.
- Difficult to handle the company's interest in a positive evaluation *(Lohm, 1997)*.
- Problems with the consumption-part (uncertain estimations concerning consumption gives cradle AND grave studies) *(Lohm, 1997)*.
- Users and developers of the LCA method often "pretend" to give <u>the one</u> answer *(Lohm, 1997)*.

2.4.4 Development

Models for characterisation are still being developed as well as means for integrating location differences *(UNEP, 1996)*. LCA will however never be site-specific, but may become more site-dependent *(Finnveden, 1998)*. How to handle recycling in an appropriate way is also under consideration. According to Finnveden *(1999)*, there are no good valuation methods available. Improvement of old methods and development of new are needed and underway. The need for overall development is large in LCA and the theory underlying the method is hard to live up to. The intention of life cycle thinking is very good and it should be used as a best estimate while the development goes on.

2.5 Positional Analysis (PA)

Based on:

- Brorsson K-Å., 1995.
- fms, Forskningsgruppen för miljöstrategiska studier, 1995
- Forsberg G., 1996.
- Söderbaum P., 1994.
- Söderbaum P., 1995.

2.5.1 Background

In 1973, Peter Söderbaum presented the positional analysis in his PhD thesis. PA is based on institutional economics and general systems theory (*Brorsson, 1995)*. Interdisciplinarity is central in the analysis looking at environmental, economical and social aspects, which leads to the probable conclusion that more then one person should be assigned for an analysis of this kind.

The positional analysis aims to clarify the decision making process, to make visible conflicts of different interests and to openly discuss different valuational standpoints *(Söderbaum, 1995)*. Since there is no "right way" of valuating different effects, the analyst using PA leaves this phase of the process to the democratically elected politicians.

The PA emphasises many-sidedness *(Söderbaum, 1994; 1995)* this applies for

- views of the problem
- alternative courses of action

- impacts
- activities and interests affected
- possible valuational standpoints (or ideological orientations)

This many-sidedness has to be kept within some limitations or the confusion will be total.

Positional thinking is ’to think about impacts in terms of non-monetary positions’. Implementing one alternative leads to a different position (or state) in the future. This positional change may lead to a change in future options. *(Söderbaum, 1995)*

2.5.2 How to perform a PA.

An ambitious study should include the following steps *(Söderbaum, 1995)**:***

- **Description of decision situation.** Stating historical background, defining interest groups and describing related decisions (previous and simultaneous).
- **Identification of problem(s).** Describing problem(s) as formulated by the different actors.
- **Design of alternatives and formulation of the problem(s).** Choosing alternatives for consideration, identification of relations with other decision situations.
- **Identification of systems.** Identifying systems affected differently depending on alternative.
- **Identification of impacts.** Identifying relevant impacts (monetary and non-monetary) and comparing the different alternatives.
- **Definition of possible inert and irreversible effects.** Including investigating potential effect on future options.
- **Analysis of activities and interests.** Identifying activities affected differently depending on alternative. Assuming goal direction for each activity. Activity combined with goal direction gives an interest. For each activity, a ranking of the alternatives is made.
- **Analysis of prevailing risks and uncertainties.** Formulating possible futures.
- **Valuational standpoints.** Describing possible valuational and ideological standpoints.
- **Conditional conclusions.** Relating expected impacts to possible futures and valuational and ideological standpoints for each alternative.

Looking at one step at the time gives the opportunity to show how choosing one alternative might lead to irreversible positional changes or impacts on future options. Decision trees are used to make visible this effect on future options *(Söderbaum, 1995).*

2.5.3 Description

Overall purpose of using the tool?

Strategic decision-support and, aiming at making the decision situation more transparent and illuminating complexity and conflicting interests *(fms, 1995).*

Which object is being analysed?

Projects and also some decisions on higher strategic levels, e.g. programmes. Examples of fields where PA has been used are roadplanning, forestry, and energy systems (for a list of studies made see *Brorsson, 1995*).

What is the reason for performing the analysis for the different users?

Authorities and companies get broad pictures of decision-situations and are allowed to use their own ideologies and values in drawing conclusions.

In what perspective may the analysis be used?
Prospective, foreseeing future effects.

Which are the system boundaries?
PA looks at the state of the environment (or economy) at different times (”positions”) and measure changes *(fms, 1995)*. The spatial boundaries are set according to systems chosen by the analyst. Boundaries in time can be the construction and operation time of a project *(Brorsson, 1995)*.

Is there a need for a reference object?
The zero alternative is usually used as reference as the different alternatives are compared *(Brorsson, 1995)*.

What is the unit of the results?
Several different units.

What kinds of effects are considered?
Economical, social and environmental.

What environmental burdens are considered?
See table 1. Theoretically all environmental impacts should be included. Since this tool is not intended for weighting together different impacts and they are separately presented, qualitative descriptions may not involve disadvantages. On the other hand, since so many aspects are considered in a PA, there is a considerable risk that impacts not thought of by the analyst or any of the stakeholders are left unnoticed.

Is the method quantitative or qualitative?
Qualitative and quantitative.

Do the performance of the analysis include follow-up?
No.

Is the method standardised/harmonised?
Söderbaum has presented a general scheme *(Söderbaum, 1995 and Forsberg, 1996)*.

Where and how frequently is it being used?
Mainly used in Scandinavian countries *(Söderbaum, 1995)*. The method has been considered to be a theoretical alternative to CBA not very often practically used *(fms, 1995)*.

Strengths and weaknesses of the method
+

- Provides a material on which decision-makers themselves can apply their own ideologies and valuations *(fms, 1995)*.
- Flexible method, possible to use on almost all kinds of problems *(fms, 1995)*.
- Conflicting interests are illuminated *(Söderbaum, 1994)*.
- Many-sidedness is part of the tool, which is crucial for democratic processes *(Söderbaum, 1995)*.
- Brorsson *(1995)* summarises some PA users’ positive opinions as good when using qualitative data, combining monetary and non-monetary, and quantitative and qualitative

parameters, gives a broad view of the problem, systematic way of showing consequences of different alternative developments, etc.
- Irreversible effects are described separately *(Forsberg, 1996)*.
- Disaggregation is promoted, different resources and effects considered from their own perspective. Accounting for uncertainty *(Forsberg, 1996)*.

-

- High demands on the analyst, many decisions and choices to make and huge amount of material to present in a pedagogic way.
- Flexible method, requires high integrity of the analyst *(fms, 1995)*. There is a considerable risk that some potential impacts are left out.
- The decision-maker has to do a lot of work himself, which is time consuming.
- Maximising many-sidedness may lead to confusion *(Söderbaum, 1995)*.
- Brorsson *(1995)* summarises some users' of PAs negative opinions as risk of including too many alternatives, risk of too broad analysis, etc.
- PA has been considered as theoretical and hard to work, but as development of the method is continuing this is becoming less of a problem *(fms, 1995)*.

2.6 Cost-Benefit Analysis (CBA)

Based on:
- fms, Forskningsgruppen för miljöstrategiska studier, 1995.
- Forsberg G., 1996.
- Mattsson B., 1988.
- Söderbaum P., 1995.
- Turner R.K. et al., 1994.

2.6.1 Background

Some kind of cost-benefit analysis (CBA) was performed already in 1844 in France. But since then considerable improvements and standardisations have been made. From the 1960ies an increasing use of CBA can be seen, partly as spreading from USA to other countries and partly as being used in all sorts of resource use and not only for water- and road projects which had been the main application areas. *(Mattsson, 1988)*

CBA is based on neoclassical economics. It is a method trying to estimate the total impact of a project on society by calculating social costs and benefits. Environmental impacts are included by valuation of these, converting them into monetary terms.

An assumption is that ”a 'better' allocation of resources is one that meets people's preferences”. An obvious difficulty here is how to define ”people's preferences”, which of course are not homogenous. CBA measures preferences as ”willingness to pay” (WTP) for something (or, less common, to avoid something) and also ”willingness to accept” (WTA) compensation for loss of welfare. There are other ways to value environmental impacts in monetary terms as well, but ”willingness to pay” is the most used and well developed method. There are also various ways to estimate WTP *(fms, 1995)*.

The Pareto criteria modified by Kaldor *(1939)* and Hicks *(1939)* is often used in the method. This criteria means that, to be considered beneficiary a development will have to lead to <u>net benefits</u> of ”the lucky people” large enough to <u>enable compensation</u> of those loosing from the activity. However there is no requirement for an actual compensation to be done, which give possibilities for very unequal distribution. *(Mattsson, 1988)*

Preference of time (“now or in the future”) should also be considered and this is done through discounting, which simultaneously is a way of including the change of capital over time. Discounting is done by deciding on a discount rate defining present value of future costs/benefits. Net present value (NPV) is then calculated as $\Sigma(B_t - C_t/(1+r)^t$, where B_t is benefit in year t, C_t cost in year t, and r discount rate. CBA defines a development as beneficiary when NPV is positive *(Turner et al., 1994).*

$$\Sigma_t (B_t - C_t)(1+r)^{-t} > 0$$

2.6.2 How to perform a CBA.

As presented in “Miljöstrategi för försvarsmakten *(fms, 1995)*

- Identification of problem and alternative solutions.
- Identification of social costs and benefits for each alternative
- Valuation of costs and benefits (usually in monetary terms).
- Allocation of costs and benefits over the project time.
- Calculation of net present value (NPV) as described above.
- Ranking alternatives by NPV.
- Sensitivity analysis should be performed.
- Presenting recommendation.

2.6.3 Description

Overall purpose of using the tool?
Decision-support. According to fms *(1995)* it is the tool most well established and utilised in economic decision situations.

Which object is being analysed?
Project and some decisions on higher strategic levels, e.g. programmes

What is the reason for performing the analysis for the different users?
Authorities and companies use CBA for economic evaluation of projects and other developments.

What is the perspective of the analysis?
Prospective, estimating future costs and benefits.

Which are the system boundaries?
Economic and geographical boundaries are set according to the development considered in the study (a market, a region, etc.). CBA is a partial economic analysis with no feedback from other markets or regions. Future generations should be considered, which implies no theoretical time boundary.

Is there a need for a reference object?
The zero alternative is used as reference and different alternatives should also be compared.

What is the unit of the result?
Usually a monetary unit, costs and benefits impossible to calculate in monetary terms may be presented as intangibles.

What kinds of effects are considered?
Economic, environmental and social.

What environmental burdens are considered?
Theoretically all environmental burdens should be included (see Tab. 1).

Is the method quantitative or qualitative?
Quantitative.

Do the performance of the method include follow-up?
No.

Is the method standardised/harmonised?
Rough guidelines are available.

Where and how frequently is it being used?
CBA is used in several countries, including developing countries *(Mattsson, 1988).*

Strengths and weaknesses of the method
+

- Presenting ”a single” result – a beneficiary project or not, and more or less beneficiary than other alternatives *(fms, 1995).*
- Easy to compare analyses *(fms, 1995).*
- Including external costs in an economic analysis *(Mattsson, 1988).*

-

- Presenting “a single” result is not transparent.
- Human focused, even developed country, now living human focused due to the WTP valuation, which overestimates the opinions of the developed country populations of today.
- A positive discount rate is often used, unfortunate for future generations and for the environment (the effect of a positive discount rate on the environment can be discussed) (fms, 1995 and Turner et al., 1994).
- Questionable if analyses based on economic grounds are applicable to environmental issues.
- Different resources and environmental consequences are considered as inter-changeable (Forsberg, 1996).
- Irreversible effects are not convertible into monetary units (Forsberg, 1996).
- Huge uncertainty because of many valuations. Since the result is presented in an aggregated form this uncertainty may be forgotten.

2.7 Material Intensity per Unit Service (MIPS)

Based on:

- Schmidt-Bleek F., 1993.

- Schmidt-Bleek F., 1996.
- Wuppertal Institute, 1999.

2.7.1 Background

The development of the MIPS concept, Material Intensity per Unit Service, started in 1992 at the Wuppertal Institute in Germany, by Schmidt-Bleek *(Wuppertal Institute, 1999)*. It focuses on the big material flows created by today's society. The development started as a reaction against the total focus on small quantities of toxic substances. In a MIPS study all the material used/affected to produce a defined service or function is added together. Inputs are accounted for from both before and after the service-life phase, which means inputs to manufacturing, use, repair, recycling and disposal as well as infrastructure are added *(Schmidt-Bleek, 1996)*. Waste and emissions are not directly considered, but generally reducing total inputs simultaneously reduces the outputs.

All the material removed from its origin is to be included; overburden from mining as well as erosion from agricultural soils. Energy is accounted for as the material flows created when producing energy and making it available. Obviously, all environmental threats are not yet discovered. By including all kinds of material, missing potential hazards is avoided. MIPS is intended to give a rough estimate of environmental stress intensity, and the developers are emphasising the importance of using additional methods for toxicological aspects *(Schmidt-Bleek, 1996)*.

The "ecological rucksack" is the pedagogic symbol of all the material moved or used to gain a substance, product or service minus the actual weight of the final good (Fig. 4). Material intensity, MI, is the total weight of material affected, the rucksack and the weight of the final good added together. MI-factors for several substances and also some energy carriers, construction material, etc. have been determined and can be found on the web *(Wuppertal Institute, 1999)*. These factors facilitates easy calculations of MIs, the weight of for example the cement used for a building is simply multiplied by the MI-factor of cement.

There are five separate rucksacks (or compartements of the rucksack):

- abiotic material (incl. all energy carriers)
- biotic material
- soil
- water
- air

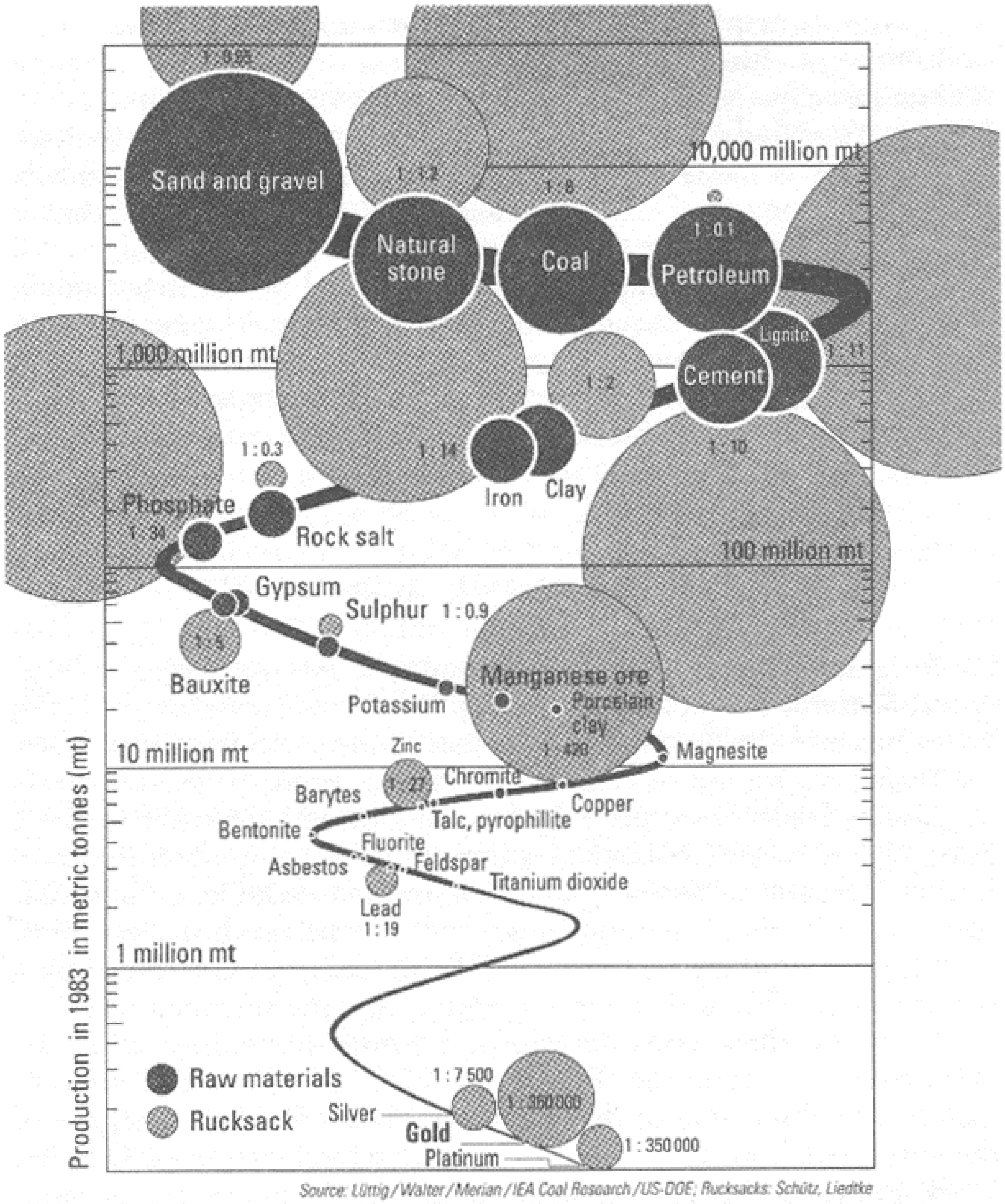


Figure 4. Ecological rucksacks of different materials, vertically the total global material production in 1983 is shown. The dark circle shows the amount of material and the grey circle the size of the “ecological rucksack” of the material. *(from Schmidt-Bleek, 1996)*

The plan is to define MIs of processes, goods and services to see where the large material flows are set in motion and where it would be technically and economically most effective to start dematerialisation. MAIA, material intensity analysis, is the name of practically using the MIPS concept *(Wuppertal Institute, 1999),* but since this expression is not often used, MIPS will be used here both when describing the concept and the tool.

MIPS is closely connected to the Factor 10 concept. Factor 10 is based on the assumption that we need to reduce our current use of resources by 50% globally. To obtain this global reduction the western world (20% of the population today using 80% of the resources) would have to decrease their use by a factor 10. *(Schmidt-Bleek, 1996)*

2.7.2. How to perform a MIPS

(from Wuppertal Institute, 1999)

- Definition of service unit.
- Construction of a process line/chart.
- Collection of data. A standard form may be used. Inputs are divided between the five rucksack categories mentioned above· Outputs are defined as main- and bi-products, and also restproducts and emissions. (The standard form also sets aside space for literature references, region, year and other comments.)
- Calculation of the material intensity ”from cradle to product”. Each input material is multiplied with its corresponding MI-factor (in kg/kg).
- Calculation of the material intensity ”from cradle to cradle”. MIs for the different phases raw material extraction, production, use, maintenance and disposal are added to obtain the total MI. Subsequently the service unit is used to achieve the MIPS-result.

The resource productivity is the inverse of the MIPS *(Schmidt-Bleek, 1993).* A lower resource use per unit service gives higher resource productivity. MIs calculated for regions and divided by GNP in stead of service units generated may be used to estimate resource productivity of that particular region *(Schmidt-Bleek, 1996).*

2.7.3 Description

Overall purpose of using the tool?

The tool may be used for communication and decision-support aiming at dematerialisation. MIPS may serve as a rough estimate of environmental burdens, pointing out major environmental impacts resulting from current human activities. Measuring material intensity trends may function as a sustainability indicator.

Which object is being analysed?

The object under study is one unit of service. This service can be provided by a product, e.g. one glass of orange juice or a function, e.g. transportation from A to B.

What is the reason for performing the analysis for the different users?

Companies may use MIPS in product design. Authorities and companies may use it in strategic decisions concerning processes, facilities and infrastructure, and also in separating environmentally sensible recycling processes from the adverse. NGOs may use it in promoting service-use instead of products and other dematerialisation activities *(Schmidt-Bleek, 1996).*

What is the perspective of the analysis?

Looks at the whole lifetime of the service yielding process. Analyses the current situation.

Which are the system boundaries?

The boundary is between technosphere and nature. There are no geographical boundaries.

Is there a need for a reference object?
No. Comparisons can be made between different MIs for different ways of providing the same service, but this is not necessary.

What is the unit of the result?
Kg/service unit.

What kinds of effects are considered?
Environmental.

What environmental burdens are considered?
The focus of this method is on overuse and depletion of natural resources, which gives indirect estimates of other environmental impacts (Tab. 1).

Is the method quantitative or qualitative?
Quantitative.

Do the performance of the analysis include follow up?
No.

Is the method standardised/harmonised?
Not really, there are guidelines available on the website, but so far only in German *(Wuppertal Institute, 1999).*

Where and how frequently is it being used?
This method is still new and under development. Some studies have been performed in Germany, where the method is developed, and some other countries.

Strengths and weaknesses of the method.
+
- Using one unit for mass and energy (kg) and avoiding weighting.
- Estimations made per service unit, makes different solutions for decrease possible.
- May be used for screening LCAs, illuminating where further, more detailed investigation is needed *(Schmidt-Bleek, 1996).*
- Can be used to monitor progress in dematerialisation.
- May become a basis for international harmonisation due to its simplicity *(Schmidt-Bleek, 1993 and 1996).*
- The symbol of the ecological rucksack is pedagogic and easy to understand.

-
- May be hard to define what services a product stands for and several products also embody many service functions that can make allocation of the weight hard.
- Occupation of land not taken into account. Corrections might have to be made for area-intensive processes or activities. In the MIPSbook a tool called SIPS (Surface Intensity Per unit Service) is suggested for this aspect. No further development of this tool has been presented. *(Schmidt-Bleek, 1993; 1996)*
- Only looks at the input side of the system. Wastes arising are only considered in terms of the material input to handle them.

- Only looking at the weight of material used might not be an appropriate estimate for environmental impacts.
- Toxicity and biodiversity are not accounted for, at least not directly.
- Calculations for complex facilities and infrastructures are still quite expensive *(Schmidt-Bleek, 1996).*
- Most material and guidelines only exist in German.

2.7.4 Development

Schmidt-Bleek *(1996)* discusses in the MIPS-book the potential differentiation between masses. So far amounts of abiotic and biotic material, soil, water and air are presented separately facilitating weighting if preferred. Schmidt-Bleek also points out problems in accounting for water affected, where to draw the line. He takes as examples the loss of soil moisture in irrigated cotton plantations and the definition of water moved in hydroelectric dams. These are issues where some kind of definition needs to be made, and presented to facilitate comparable studies.

2.8 Total Material Requirement (TMR)

Based on:

- WRI, World Resource Institute, 1997.

2.8.1 Background

Total material requirement (TMR), as described by the World Resource Institute (WRI) *(1997)*, is based on the work of researchers from four institutions (WRI, USA; Wuppertal Institute, Germany; Netherlands Ministry of Housing, Spatial Planning and Environment; and the National Institute for Environmental Studies of the Japan Environment Agency). Thoughts from other concepts and tools (LCA, Industrial Ecology, Materials Flow Analysis and environmental indicators) have been gathered and processed to finally obtain the TMR approach *(WRI, 1997)*.

This tool is more or less the same as a MIPS-analysis, only it is applied on a regional level and not focusing on a produced service unit. TMR accounts for the total amount of material an economy disturbs to facilitate economic processes. Direct and indirect material/resource use in production and construction, deliberate landscape alterations, soil erosion in agriculture, etc. is included. Only abiotic and biotic resources are considered (in the country study presented in the WRI report *(1997)* agricultural tillage is left out), air and water is left out. *(WRI, 1997)*

To obtain the TMR domestic and imported natural resources are added together, including their "hidden flows" (material requirement that never enter the economy). The case study in the WRI report illuminates the importance of the hidden flows, as they account for 55-75% of TMR when analysing the economies of the Netherlands, Japan, USA and Germany *(WRI, 1997)*. Hidden material flows can be divided in ancillary flows and excavated/disturbed flows. Ancillary flows are physically removed from their place of origin together with the material or product demanded (parts of trees or an ore transported to processing facilities but never used), whereas excavated flows are moved to enable extraction, construction, etc. (e.g. overburden in mining, earth moved when ploughing). Hidden material flows have been calculated for fossil fuels, metals and industrial minerals, construction materials, renewable natural resources, infrastructure creation and maintenance, and soil erosion. *(WRI, 1997)*

Currently, hidden flows of imported material and semi-manufacture goods are accounted for, while hidden flows of imported final products are not (further work is needed before this can be done). Exports and their hidden flows are also included. Recycled material is accounted for only when imported. This will altogether give "the total physical requirements and throughputs of materials on which a nation's economic activity depend". *(WRI, 1997)*

Data in the TMR assessment should be transparently reported. In the WRI paper, domestic sources, foreign sources, hidden flows, etc. are reported separately to give more information. Because of this disaggregated data presentation it is also possible for decision-makers to get more exact estimates of environmental impacts, dividing the data between impact categories and weighting the impacts. *(WRI, 1997)*

If the analysis is performed for a series of years, information about efficiency changes in material use are shown. Material intensity can be measured as TMR/GDP ratios, where the decoupling of natural resource use and economic activity can be monitored. This function, as an indicator of trends in natural resource use, is making TMR a fitting tool for concepts of dematerialisation, e.g. Factor 10 (for a short explanation of the Factor 10 concept, see p. 28) *(WRI, 1997).*

2.8.2 How to perform a TMR

(from WRI *(1997)*)

- Gathering data on direct material input and hidden material flows for fossil fuels, metals and industrial minerals, construction materials, renewable natural resources, infrastructure creation and maintenance, and soil erosion.
- Gathering data for imports of raw material and semi-manufactured products including hidden flows, and of final products.
- Exports are presented separately.
- Recycled material is not included in TMR, but preferably presented separately.
- Gathering data on population and GDP (and/or other social and economic facts).
- Calculating the TMR and indicators e.g. TMR/GDP, domestic TMR/capita, hidden flows of raw material imports/capita, etc.

2.8.3 Description

Overall purpose of using the tool?
Decision-making, and communication to illuminate hidden material flows, differences in domestic/foreign flows and trends in material intensity *(WRI, 1997).*

Which object/system is being analysed?
An economy.

What is the reason for performing the analysis for the different users?
Government/authorities may use TMR to indicate changes in material intensity (per GDP). NGOs may use it to illuminate the high natural resource use and distribution of impacts (since much of the impacts are in developing countries exporting raw material and products to developed countries) *(WRI, 1997).*

In what perspective may the analysis be used?
The tool presents snapshot in time usually based on yearly statistics, these may be used retrospectively.

Which are the system boundaries?
The time frame is usually a year. There are no geographical boundaries concerning where the material disturbed is situated, but the objective is a defined region or economy including its exports and imports.

Is there a need for a reference object?
No, but comparison between countries, or between years, may be informational.

What is the unit of the result?
Tonnes (or kg/capita, kg/GDP, etc.).

What kinds of effects are considered?
Environmental.

What environmental burdens are considered?
Over use and depletion of natural resources, which may give indirect estimates of other environmental impacts (Tab. 1).

Is the method quantitative or qualitative?
Quantitative.

Do the performance of the analysis include follow up?
No.

Is the method standardised/harmonised?
No.

Where and how frequently is it being used?
Probably only used in WRI *(1997)*.

Strengths and weaknesses of the method.
+

- Including resources affected by economic activities and still not accounted for in general national analyses (hidden flows). A physical account complementing economic accounts.
- Illuminates hidden flows also in imported commodities.
- Figures are presented in a disaggregated form facilitating discussions around where the differences are and which are the major contributors to the total TMR.

-

- Countries with low import levels show relatively high TMR, since material flows associated with feeding workers, driving transport/process vehicles, etc. are not included in the hidden flows of imports but they are a part of the domestic material flow *(WRI, 1997)*.
- Only accounts for inputs to the system. Considering the impacts of waste and emissions only by measuring the inputs used to handle them, when they are handled.
- Not including air and water “disturbed”, as MIPS do.

- Hidden flows of imported final products not yet included.
- Toxicological and biodiversity impacts not included.
- Does not consider spatial differences and synergistic effects.

2.8.4 Development

The authors of the WRI-document *(1997)* suggest the following development of the tool:

- Development of a more complete accounting to include flows on the output side of the material cycle.
- Dissaggregate “material flow groups” further, to enable use in different economic sectors needing more specific data.
- Establishment of international co-operation, enabling calculation of material flows of import.
- Decisions on whether to include hidden flows in imported final products needs to be taken.
- Investigations of ways to connect the material flows to potential environmental impacts and weight these impacts.
- International harmonisation and broader use of the method is wished for, to gain improvements of the methodology and increase the database.

2.9 Ecological Footprint (EF)

Based on:

- Folke C. et al., 1997.
- Kautsky et al., 1997.
- Robért K-H. and Ogewell V., 1997.
- Wackernagel M. and Rees W., 1996.
- Wackernagel et al., 1997.
- Wackernagel M. and Yount D., 1998.

2.9.1 Background

The concept of the Ecological Footprint has been taught by William Rees for 20 years. Since 1990 it has been developed by M. Wackernagel and other students *(Wackernagel and Rees, 1996)*. At the Centre of Sustainability Studies in Mexico, Wackernagel has further developed the Ecological Footprint concept (may be visited on the web at www.edg.net.mx/~mathiswa).

The ecological footprint introduces a way of looking at the total area needed to continuously support a certain population or economy. A city does not only occupy the actual ground that is covered by buildings and infrastructure. It also needs sea area (for fishing, denitrification of sewage water, etc.), forests to assimilate CO_2 released from combustion of fossil fuels and to produce wood products, etc.; agricultural land for food; and much more which is often not included in our usual idea of a city *(Wackernagel and Rees 1996).*

Human populations or economies are usually the focus for analysis. All productive land and water areas required on a continuous basis to produce and maintain goods and services consumed and take care of wastes generated are added together to obtain the footprint. Present assessments are underestimates of appropriated area. This is partly because today’s practice in agriculture and other activities are so far handled as “sustainable” practice in the analysis, which is not correct. Furthermore, the main focus is on the input side, for example areas for crops, wood production and built-up area. On the output side the current footprint analyses are dominated by areas needed for uptake of CO_2 released from the combustion of fossil fuels. Converting factors describing in terms of m^2 the effects of other emissions, such as NO_x and SO_2 are lacking. Improvements are being made and there is an awareness of the limitations of the tool *(Wackernagel and Yount, 1998)*. Opposite to these aspects of underestimates, the dangers of doublecounting may lead to overestimates. It is important to acknowledge which areas may be used for several purposes simultaneously and to only count this area once. For example, grazing can sometimes be provided by the same area as CO_2 sequestration.

Area appropriated is divided in categories of ecologically productive sectors, they are usually the following.

- **Fossil energy land**, set aside for CO_2 sequestration
- **Arable land**, producing crops (the ecologically most productive areas)
- **Pasture**, grazing land
- **Forest**, plantations or natural forests that may yield timber products and also provide many other ecological services.
- **Built-up areas** used for human settlements, roads, etc.
- **Sea**, where surface area determines the productivity of the sea.

Results of an ecological footprint analysis may show if a defined population's demand for productive area exceeds its' supply (e.g. productive area appropriated related to area available in a country, region, etc.). Comparison can also be made to accentuate global equity, by relating the footprint per capita to the total global productive area available per capita. Wackernagel et al. *(1997)* presents a figure of 1.7 ha/cap as the currently available biologically productive area for human use. In calculating this figure 12% (as suggested by the World Commission on Environment and Development) of the area has been deducted for reasons of biodiversity protection. The authors state that this might not be a sufficient amount, but still use it as a politically feasible share. The available area of 1.7 ha/cap can be compared to the 5.8 ha that an average Swedish person appropriated in 1997, accounted for as 1993 world average productivity *(Wackernagel et al. 1997)*. On the other hand Sweden is one of the few countries which have more available ecological capacity within its borders than its inhabitants appropriate, 7.8 ha per capita *(Wackernagel et al. 1997)*.

The method has also been used to evaluate area requirements of activities e.g. shrimp and Tilapia aquaculture *(Kautsky et al. 1997)*, and other applications *(Wackernagel and Rees, 1996)*. The use of footprinting on activities and products/services may become more frequent.as the methodology is extended to include more emissions.

2.9.2 How to perform an EF.

(Wackernagel and Rees, 1996)

- **Estimate an average person's annual consumption** of particular items. When an economy is studied, production-, import – and export figures can be used.
- **Estimate the land area needed per capita** for the production of each major consumption item. Dividing average annual consumption of the item by the average annual productivity or yield, the yield can be world average or local. When several inputs are considered areas are estimated separately for each input.
- **The areas of the items are added** for one person (not adding overlapping areas).
- **The footprint of the defined population is calculated** from the per capita value.

2.9.3 Description

Overall purpose of using the tool?
Mainly communication and learning, illuminating dependence on and often overuse of productive land and sea area.

Which object is being analysed?
A defined population or economy, but a product or a service may also be the subject of analysis *(Wackernagel and Rees, 1996; Kautsky et al., 1997)*. According to Wackernagel *(1997)* most of the earlier EF studies have focused on countries or processes and his study of Santiago de Chile provides the first detailed assessment of a city footprint.

What is the reason for performing the analysis for the different users?
Governments/authorities, NGOs and also individuals may use this analysis to communicate, and understand, the effects of different processes or lifestyles.

In what perspective may the analysis be used?
The footprint tool presents a snapshot in time, which may be used primarily in a retroperspective manner.

Which are the system boundaries?
There is no actual time frame since the footprint is a snapshot in time, however yearly statistics are usually utilised when evaluating an economy, and the whole lifecycle when a function is considered. There are no geographical boundaries concerning area appropriated, but the objective is often a defined population/economy with relevant boundaries.

Is there a need for a reference object?
The result as ha/capita may be used as it is, or the area actually occupied by the population may be used as reference. Different economies or populations may also be compared. Available ecologically productive land per capita (globally or locally) may be related to.

What is the unit of the result?
m^2 or ha (in the case study presented in this paper the unit is m^2*yr since a yearly consumption is not the focus of analysis).

What kinds of effects are considered?
Environmental.

What environmental burdens are considered?
The EF is focused on productive area exploited by infrastructure, overuse of renewable resources and the problem of the increasing greenhouse gas concentration in the atmosphere. Eutrophication, acidification and waste assimilation are categories for which methods of inclusion are being developed or planned to be. The inclusion of overuse of groundwater is also underway (Tab. 1).

Is the method quantitative or qualitative?
Quantitative.

Do the performance include follow-up?
No.

Is the method standardised/harmonised?
Development is ongoing and there are guidelines presented by Wackernagel and Rees *(1996)*.

Where and how often is it being used?
Has for example been used for several studies in Sweden.

Strengths and weaknesses of the method
+
- Good from an educational point of view, transparently showing unsustainable behaviour *(Wackernagel and Rees, 1996).*
- Takes the unequal appropriation of productive land area into account.
- According to Wackernagel and Rees *(1996)* the EF raises essential questions about long term sustainability ignored by other approaches.
- Could be used to monitor progress towards increased sustainability *(Wackernagel and Rees, 1996).*
- Sets aside area for biodiversity protection in the estimate of human available ecologically productive area.

-
- Climate stability and other important ecosystems services (including biodiversity since the 12% set aside for other species is not scientifically supported), are not sufficiently accounted for since they are hard to quantify as per capita demand and/or to convert into ecosystem area *(Wackernagel and Rees, 1996).*
- Toxicological aspects are not included.
- Wackernagel estimates that the uncertainty of a big footprint is about 5% and for a smaller 30% *(Robért and Ogewell, 1997).*
- Land used is not differently valued. Using primary production surplus or clearcutting an area of the same size "gives the same result". Farmland, flooded land for hydropower dams, untouched forests, etc. should perhaps be weighted separately.
- Risqué of double counting *(Wackernagel and Rees, 1996).*
- Water shortages are not shown *(Robért and Ogewell, 1997).*
- Hard to compare EFs separately performed, since different items and impacts may be accounted for.

2.9.4 Development

The EF is a relatively new tool and it is, as most of the others, under constant development. Alejandro Callejas has started to develop a way to include water use and e.g. Folke et al. *(1997)* incorporated nitrogen from sewage plants.

Reduction in bioproductivity subsequently caused by the depletion of the ozone layer should be added to the EF, land and productivity losses due to contamination of soil, water and air-sheds from waste should also be added *(Wackernagel and Rees, 1996).* In a draft document by Wackernagel and Yount *(1998)* future development and research are discussed. They acknowledge shortages in current analyses such as lack of data on sustainable yields, allocation problems (e.g. tourism increases the footprint of the visited country), missing data for converting outputs to area, the impact of recycling on EF, etc. One environmental impact, which will never be included, is persistent toxic outputs, since there is no way to handle these in a sustainable manner (except not producing them). *(Wackernagel and Yount, 1998)*

Wackernagel and Yount *(1998)* also suggest further development and research which would lead to a more comprehensive and maybe also more scientific tool. Research aiming towards filling methodological gaps are suggested and this would maybe include research concerning natural capital overuse, waste assimilation, GIS technology, databases, etc.

2.10 Exergy analysis

Based on:

- Finnveden G. and Östlund P., 1997.
- Hovelius K., 1997.
- Kåberger T., 1991.
- Wall G., 1993.

2.10.1 Background

Gibbs (1873) introduced the exergy concept. Rant (1953) suggested the term exergy, and Baehr (1965) gave a general definition *(Kåberger, 1991)*.

Energy is not a suitable measurement of how much work that can be performed. For example, electrical energy can be used to create structures and perform work, which the same amount of heat energy at normal temperatures could never do. Exergy, on the other hand is a measurement of the amount of energy that can be transformed into work. Unlike energy, exergy ”the quality of energy” is consumed in all real processes *(Kåberger, 1991)*.

In quality-rich energy (potential energy in highly situated water resources, electrical energy, etc.) and in matter in an ordered form the exergy amount is high. Exergy can be accounted for both in energy and material. It can describe loss of natural resources in physical terms. *(e.g. Wall, 1993 and Finnveden and Östlund, 1997)*

According to Kåberger *(1991)* it is possible to couple exergy to economy since exergy-rich energy is more valuable to society than exergy-poor. But the value of a resource depends not only of its exergy content, but also on the availability of a technology converting the resource into the desired product or service.

In “Descriptions of resource management” Kåberger *(1991)* concludes ”energy analysis is very useful, maybe not necessary and certainly not sufficient to form decisions on environmental issues”.

2.10.2 How to perform an exergy analysis

General performance (*from Hovelius, 1997)*:

1. **Estimation of energy input** to the system.
2. **Calculation of exergy input.** Each energy contribution is multiplied by its energy quality (exergy) factor.
3. **Estimation of energy output** from the system.
4. **Calculation of exergy output.** (as 2)
5. Output is divided with input and the **exergy ratio** is obtained.

2.10.3 Description

Overall purpose of using this tool?
Mainly for decision-support and learning.

Which object is being analysed?
Products, projects and may also be used for economies.

What is the reason for performing the analysis for the different users?
Companies use it for learning about the efficiency of their production and to support related decisions.

In what perspective may the analysis be used?
Prospectively, estimating the efficiency of potential developments and retrospectively searching potential beneficiary changes.

Which are the system boundaries?
Geographical boundaries are stated according to the object under study, no tidal boundaries.

Is there a need for a reference object?
Yes, the aim is to discover a more exergy efficient alternative.

What is the unit of the result?
Joule of exergy.

What kinds of effects are considered?
Environmental.

What environmental burdens are considered?
Considers the inefficient use of natural resources (Tab. 1).

Is the method qualitative or quantitative?
Quantitative.

Do the performance of the analysis include follow up?
No.

Is the method standardised/harmonised?
No.

Where and how frequently is it being used?
This method is to some extent used by engineers for optimisation of energy processes, but this is probably more of economic than environmental purposes.

Strengths and weaknesses of the method
+

- In exergy analyses, as opposed to energy analyses, differences in energy quality is illuminated *(Kåberger, 1991)*.
- Exergy analyses show how efficient and well-balanced a society is in managing natural resources *(Wall, 1993)*.

- Wall *(1993)* states that all withdrawals of resources and discharges of emissions affect the environment and that this is closely connected with the exergy of the withdrawal or emission.

-

- Maybe not be attractive to the public and non-scientists**.**
- Theoretically it is possible to obtain exergy contents of materials such as ores and refined materials, but in practice it has turned out to be very difficult, especially for mixtures of substances *(Kåberger, 1991)*.
- Measurements of exergy are made by modelling. Systems that can not be modelled appropriately cannot be measured *(Kåberger, 1991).*
- Toxicological and biodiversity aspects are not included.

2.11 Emergy analysis

Based on:

- Brown, M.T. and Ulgiati, S., 1997.
- Hellstrand, S., 1996.
- Lagerberg C., 1996.
- Odum, H.T., 1996.
- Odum H.T., 1998.

2.11.1 Background

Emergy analysis has been developed by H.T. Odum, who has been working on energy analysis since the 1960ies *(Odum, 1996)*. Emergy analysis (from "energy memory") origins in systems ecology and the maximum power principle describing in what ways successful systems are organised. The human society is considered as part of and dependent on the surrounding ecosystem *(Lagerberg, 1996).*

The definition of emergy is "available energy of one kind previously required directly and indirectly to make a product or service", where available energy is defined as "potential energy capable of doing work and being degraded in the process" *(Odum, 1998)*. As there are several kinds of energy, there are several kinds of emergy, e.g. solar emergy (unit: solar emjoules), coal emergy (unit: coal emjoules), and electrical emergy (unit: electrical emjoules). Solar emergy is the one far most often used today.

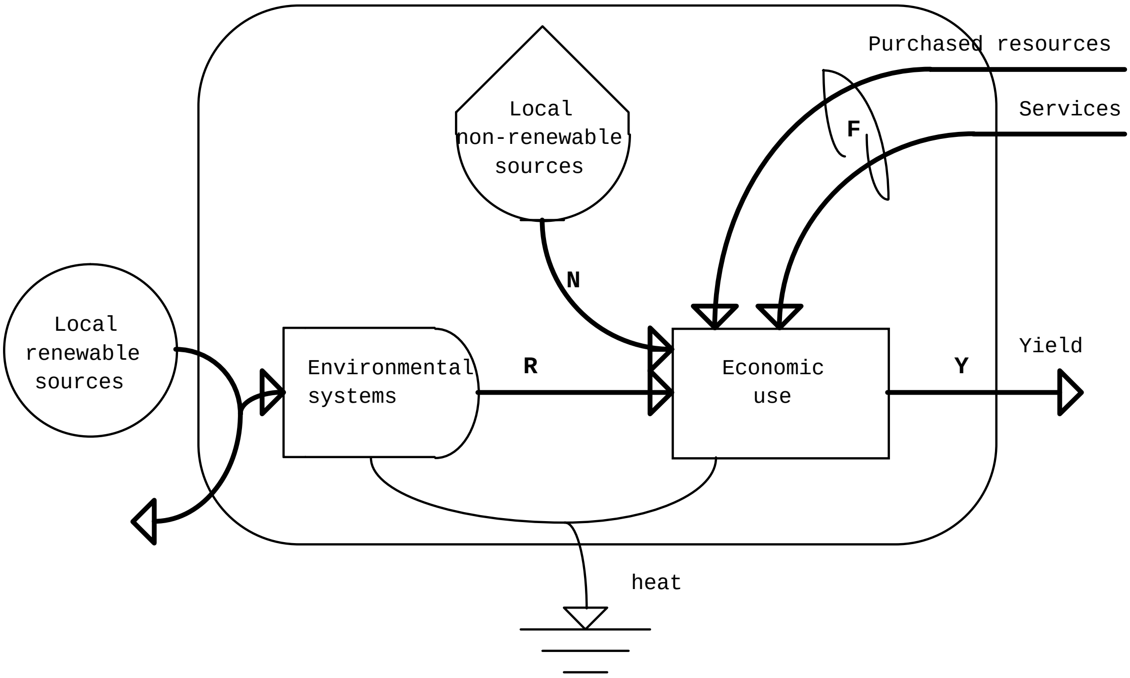
An important term in emergy analysis is transformity. This is a kind of quality measurement, stating how much emergy that has been used divided by energy available from the product or service studied *(Odum, 1996).* Transformities have been calculated for different items/materials, which can be used to calculate the emergy of that item/material *(Odum, 1996).* In theory there is a lowest transformity describing the most efficient way of achieving an item, however current practice is often more costly *(Odum, 1998)*. This fact can be used to estimate how much can be gained by improving current practice. This also constitutes a problem, since transformities are dependent on technology new transformities will have to be calculated regularly.

Emergy analysis obviously covers energy flows. Energy is accounted for in fuels, human services, rain, etc. Included are material-, monetary- and informational flows. The connections between material and emergy are evident since material has both available energy and emergy. The emergy of information on the other hand is not so easy to grasp. As Odum

(1996; 1998) explains it, learned information and genetic information has energy carriers (e.g. paper, neurones, computer discs) and information has emergy according to the emergy required to make it and sustain it. Since the energy of its energy carriers is small compared to the emergy needed to produce the information, the transformity of information is high. Monetary flows may be included calculating an emergy/money ratio for a country by dividing the total emergy use of the country by its GNP. This ratio may subsequently be used to get the emergy of human services by multiplying income with emergy/money ratio. (Sometimes the metabolic energy of the service may be used instead and multiplied with its solar transformity).

Figure 5 shows a simple system where different emergy sources are defined as renewable (R) and non-renewable (N) local sources and as purchased from the economic system (F). The definition of renewable is here, as stated by Brown and Ulgiati *(1997)*, when the replacement time is at least as fast as the use rate. The ratios presented in figure 5 are explained below *(Brown and Ugliati, 1997)*.

- Emergy Yield Ratio (EYR) is the ratio of the output emergy, Y, divided by the emergy input originating from the economic system, F. It measures the ability of the process under study to exploit local resources, “societal efficiency”.
- Emergy Investment Ratio (EIR) is the ratio of the emergy input from the economic system, F, divided by the local energy inputs, R and N. It measures how efficiently the “economic inputs” are being used.
- Environmental Loading Ratio (ELR) is the ratio of purchased, F, and non-renewable local, N, emergy divided by renewable local emergy inputs. It measures the ecosystem stress created, indicating the pressure on the local ecosystem.
- Emergy Sustainability Index (ESI) achieved by dividing the EYR by the ELR. This index as suggested by Brown and Ugliati *(1997)* is providing an aggregate measure of economic and environmental compatibility.



Yield (Y) = R+N+F
Nonrenewable to Renewable Ratio = (N+F)/R
Emergy Yield Ratio (EYR) = Y/F
Emergy Investment Ration (EIR) = F/(R+N)
Environmental Loading ration (ELR) = (F+N)/R

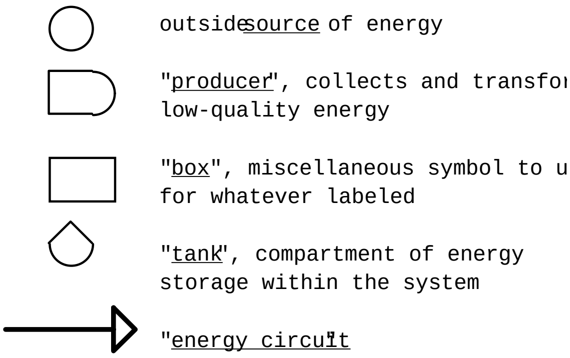


Figure 5. A general description of an emergy analysis system and some emergy based indicators, accounting for local renewable emergy inputs (R), local non-renewable inputs (N), and purchased inputs from outside the system (F) *(from Brown and Ulgiati, 1997)*.

2.11.2 How to perform an emergy analysis

(Odum, 1996; 1998)

1. **Definition of a system**.
2. **Making a systems diagram**, usually with energy language symbols (e.g. see Fig. 5).
3. **Identification of important flows** and aggregating the complex first diagram.
4. **Collection of data**.
5. **Setting up an emergy evaluation table**. Stating items to be evaluated (e.g. sunlight, fuel used, human services) and expressing them in raw units. One column is for transformities, from which emergy values are calculated. Finally the emergy/money ratio may be used to calculate an emdollar value.

The result of the analysis may be presented as different ratios, as mentioned above.

2.11.3 Description

Overall purpose of using the tool?
Decision support and learning. This tool is including ecological services usually not considered in environmental assessments.

Which object is being analysed?
Products, projects or economies.

What is the reason for performing the analysis for the different users?
Governments/authorities may use the analysis when deciding on policies. Companies may use it for strategy purposes, but also when evaluating production systems.

In what perspective may the analysis be used?
Prospectively estimating the efficiency of potential developments and retrospectively illuminating the efficiency in e.g. the society.

Which are the system boundaries?
The geographical boundaries are defined according to the objective under study, e.g. 1 ha, an economy, a region. There are no tidal boundaries, but data used usually consist of yearly statistics.

Is there a need for a reference object?
When presenting emergy ratios, these in themselves provide information. But to make improvements or choices, comparison with alternatives are necessary.

What is the unit of the result?
Usually solar emjoules (sej) and ratios without units or with various units.

What kinds of effects are considered?
Mainly environmental effects, including some social and economical effects through considering e.g. information, labour, and other societal inputs.

What environmental burdens are considered?
Considers inefficiency in the use of natural resources (Tab. 1).

Is the method quantitative or qualitative?
Quantitative.

Do the performance of the analysis include follow up?
No.

Is the method standardised/harmonised?
The method is under development, but there are some guidelines, e.g. in Odum *(1996)*.

Where and how often is it being used?
Emergy analysis is rather unknown by practicioners, and hence not very often performed.

Strengths and weaknesses of the method.
+

- Including un-monified resources and processes (sunlight, rain, winds, etc.) Accounts for externalities, ecological services, not accountable in other methods *(Hellstrand, 1996; Brown and Ulgiati, 1997)*.
- Human services areincluded in the analysis *(Brown and Ulgiati, 1997)*.
- Presenting the result in one unit and still avoiding human preferences by not using monified terms *(Odum, 1996)*.
- There are similarities between the emergy theory and neoclassical economic theory *(Hellstrand, 1996)*, which might make this method understandable for both economists and ecologists.
- Shows monetary flows in the economy and energy flows explicitly making connections visible *(Hellstrand, 1996)*.
- Information is given a value within the analysis and thereby also trying to get at the complicated biodiversity aspect *(Odum, 1996)*.

-

- Not taking the waste and emissions problem into account by only looking at the input side and thereby not considering toxicological aspects.
- Emergy/money ratios may be criticised since they are based on GDP, which may be considered an inappropriate measurement.
- Labour is sometimes accounted for using wages, which may not truly mirror the effort.
- Some criticism originating in different disciplines, as described by Odum *(1996)* is aimed e.g. at the thought of adding all energy used, at the large scales used, at the uncertainty and variability of transformities, and at the complexity and large amount of numbers arising from the analysis.
- Transformities are often dependent on technology used which leads to a need for constant recalculations.

2.11.4 Development

Odum *(1996)* states that much available data may be converted to emergy relevant figures, the great need is to organise the development of transformity tables.

2.12 Risk Assessment (RA)

-chemicals.

Based on:

- Ahlborg U.G. and Haag Grönlund M., 1995.
- CHAINET, European Network on Chain Analysis for Environmental Decision Support, 1998.
- SETAC-Europe Working Group on Conceptually Related Programmes, 1997.
- SEPA, Swedish Environmental Protection Agency, 1996.
- Commissions Directive 93/67/EEC of 20 July 1993.

2.12.1 Background

Risk assessments can be performed in many different ways, focus may be on human health or environmental effects, the source of the risk may be diffuse or specific, and the risks may be operational or accidental *(SETAC, 1997)*. Here the analysis of operational risks of chemicals are described with the focus on human health aspects. To focus on human health rather than environmental effects is probably the general Swedish application of RA. Extension of RA into the environmental field is accelerating, for example the Fourth EU Framework Programme includes RA in ”Environment and Climate” *(SEPA, 1996)*.

All exposure to chemicals is toxic if the concentrations are high enough. Risk can be defined as the probability of an adverse effect to occur. Risk assessment is a tool for estimating this probability. A distinction is often made between human health RA (HRA) and environmental RA (ERA), where HRA only has one species to deal with *(CHAINET, 1998)*.

The RA is now being extended into the environmental field. For example the Fourth EU Framework Programme includes a RA in "Environment and Climate" and in a report from the California Environmental Protection Agency a comparative risk analysis ranks some twelve environmental problems. *(SEPA 1996)*

2.12.2 How to perform a RA for chemicals

(CHAINET, 1998 and SEPA, 1996)

1. **Hazard identification.** Analysing occurrence and severity of adverse effects in relation to different levels of exposure qualitatively. Toxicological methods used include animal trials, cell cultivation trials, epidemiological investigations and experiments on volunteers.
2. **Dose-response (or effects) assessment.** Defining the quantitative relationship between dose (exposure) and response (effect). An acceptable level of exposure is determined. Uncertainty factors are to compensate for all the potential uncertainty in the data (interspecies variation, intraspecies variation, adequacy of the database, etc.).
3. **Exposure assessment.** Estimating intensity, frequency and duration of exposure. Differences in exposure for specific groups of the population are identified.
4. **Risk characterisation.** Summary of the entire process estimating the probability for an adverse effect based on 2 and 3. Assessment of uncertainty and seriousness of the effects.

Following the RA, risk evaluation and risk management (concerning measures taken in response to risks) may be performed.

2.12.3 Description

Overall purpose of using the tool?
Decision-support

Which object is being analysed?
Chemical substance

What is the reason for performing the analysis for the different users?
Government/authorities use the analysis to define acceptability criteria and in allocating regulatory resource priorities. Companies may use it to check the acceptability of the risk, and NGOs may use it to challenge the acceptable level. *(SETAC, 1997)*

In what perspective may the analysis be used?
Prospectively, foreseeing risks.

Which are the system boundaries?
Spatially a defined population or area, time should not be limited.

Is there a need for a reference object?
The risk is compared to the defined tolerable level.

What is the unit of the result?
A probability unit,

What kinds of effects are considered?
Effects on human health, sometimes including peace of mind *(SEPA, 1996)*.

What environmental burdens are considered?
RAs of chemical substances usually considers toxicological effects, focusing on human health issues (Tab. 1).

Is the method quantitative or qualitative?
Quantitative and qualitative,

Do the performance of the analysis include follow-up?
No,

Is the method standardised/harmonised?
RAs are standardised within the EU *(Commissions Directive 93/67/EEC),*

Where and how often is it being used?
Rather well established for chemicals, focusing on human health.

Strengths and weaknesses of the method
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- Since we do need some of the chemicals we produce, there is also a need for an accompanying risk assessment.
- Well established standard framework.

-

- To make an ”accurate” prediction is very time and resource consuming *(SETAC, 1997).*
- The actual risk of adverse health effects for humans can be very hard to estimate. This is due to several reasons: results from animal tests can give large uncertainties when extrapolated to humans (animal-human, high doses-lower doses); epidemiology is very restricted; synergetic effects of chemicals are sometimes not known. *(SEPA, 1996)*
- The uncertainties in the models and in data used tends to lead to conservative statements, often over estimating the risk *(SEPA 1995).*
- Some of the traditional quantitative RAs of individual chemicals still differ unacceptably much, leading to confusion and distrust *(Ahlborg and Haag, 1995).*
- Too complex to perform in product life cycle studies *(SETAC, 1997).*
- Effects only showing in a distant future may be missed.
- Lack of data.

2.12.4 Development

Ahlborg and Haag *(1995)* present some developmental needs, e.g. more RAs of complex mixtures including additive and interactive effects, identification and evaluation of "new risks", and RAs for sensitive groups. Since we are never affected by one single substance at a time, there is a developmental need for facilitating the assessment of synergistic effects. Much research development is needed to include more environmental aspects of the risks.

Table 1. Environmental burdens directly considered in theory. Environmental burdens modified from the environmental threats as presented by the Swedish Environmental Agency with natural resource use added. Considering the methods practice, the table would have had a different appearance. Some examples of this are footnoted.

	1) GHG	2) Ozone deple-tion	3) Acidi-fication	4) Photo-chemical oxidants	5) Airpollution /noise in cities	6) Eutroph-ication	7) Metals toxic	8) Organic subst., toxic	9) Foreign org.	10) Infrastructural exploitation	11) Biodiversity loss	12) Waste/ rest-prod.	13) Overuse ren. resources	14) Depletion non-ren. resources
EIA	x	x	x	x	x	x	x	x	x	x	x	x	x	x
SEA	x	x	x	x	x	x	x	x	x	x	x	x	x	x
LCA	x	x	x	x	x/x*	x	x	x	x*	x*	x*	x#	x*	x
PA	x	x	x	x	x	x	x	x	x	x	x	x	x	x
CBA	x	x	x	x	x	x	x	x	x	x	x*?	x	x*?	x
MIPS	-	-	-	-	-	-	-	-	-	-#	-	-	x	x
TMR	-	-	-	-	-	-	-	-	-	-	-	-	x	x
EF	x	-#	-#	-	-	-#	-	-	-	x	-¤	-#	x’’	-
Ex	-	-	-	-	-	-	-	-	-	-	-	-	x	x
Em	-	-	-	-	-	-	-	-	-	-	-	-	x	x
Rachem.	-	-	-	-	x/-	-	x	x	-	-	-	-	-	-

* usually not considered in practice.

\# development and research ongoing/needed for possible inclusion.

’’ inclusion of ground water use underway.

¤ may be indirectly covered, e.g. by the setting aside of 12% of productive area for reasons of biodiversity protection, or by emphasising the need of a functioning ecosystem of a particular kind (e.g. *Kautsky et al. 1997).*

1) Greenhouse effect (GHG)
2) Depletion of the ozone layer
3) Acidification of land and water
4) Formation of photochemical oxidants/ ozone close to the ground
5) Airpollution and noise in cities
6) Eutrophication of water and land
7) Toxic effects caused by metals
8) Toxic effects caused by organic substances
9) Introduction and dispersion of foreign organisms (incl. GMO, genetically modified organisms)
10) Use of land and water resources for production and ”supply” (forestry and agriculture)
11) Exploitation of land and water for buildings and infrastructure
12) Biodiversity loss
13) Disturbing ”resource cycles”, waste and environmentally dangerous restproducts.
14) Overuse of renewable resources
15) Depletion of non-renewable resources

3. CASE STUDY

The case study of this report mainly functions as a way of comparing how the different tools work. The analysis is not performed as thoroughly as desired, but differences between the tools used are illuminated and the relations between the resulting total fuel impacts differ between the methods. Difficulties in data availability, limitations in guidelines, etc. are also illuminated.

This part of the report is divided into sections. Firstly a general description of goal and scope of the case study is presented. Assumptions made in this section are valid for the four tools used. Secondly, the four analyses are separately performed and any specific data or assumptions are presented for the relevant tool.

3.1 Introduction to the case study

Energy is a relevant field from an environmental perspective, since several of the major environmental threats are connected to energy production and/or use, e.g. climate change, acidification, photo-oxidant formation. Consequently many strategic decisions need to be taken in questions involving energy.

One example is the choice of future heating systems, a part of which is the object of study in this report. There are several interesting alternatives to consider, but here focus is on large-scale district heating. Neither this choice nor the selection of fuels is describing personal opinions on preferable future heating modes. The choice is more based on the fact that focusing on large-scale district heating provides a system with more or less the same infrastructure, independent of the fuel used. Inventory data is also comparably easy to find, which is another major incentive.

There are interesting small-scale solutions (e.g. fuelcells, “local sewage water” heat exchange, solar heating with storage) and new heating sources (e.g. hydrogen, solar heating) coming up. Those, as well as a comparison between large-scale and small-scale district heating, would have been interesting to include in the study but could not be fitted in. General studies concerning future heating solutions should of course also take energy efficiency into account.

The first aim of the case study is to compare the tools used, rather than compare the fuels under study.

3.1.1 District heating

To increase the district heating share of the total heating supply is part of the strategy to decrease emissions of CO_2 to the atmosphere. Already during the 1940s municipalities in Sweden acknowledged district heating, but it was in 1975-1985 that the real expansion took place (*Energimyndigheten, 1998)*. The extended use of district heating has lead to a presently well developed infrastructure in comparably many densely populated areas, which will facilitate a cost-effective way to increase use of district heating.

In Table 2 the share of the fuel supply for district heating production in 1997 is shown. These data are based on statistics of members of the Fjärrvärmeverksföreningen (fvf), who delivered over 90% of the total 42.2 TWh (supply 48.6 TWh) of district heating in 1997 (*Energimyndigheten, 1998 and E. Larsson, Fjärrvärmeverksföreningen, personal* *communication).* Recently there has been major changes in fuels composition for district heating generation, in 1980 oil had 90% of the energy supply, and in 1997 it had decreased to 10% (*Energimyndigheten, 1998).*

Table 2. District heating fuels and their supply for heat production by fvf members in 1997, presented as share of their total supply of 47.4 TWh *(E. Larsson, personal communication).*

FUEL	SHARE OF SUPPLY
Waste (mainly household)	10%
Fossilgas	6%
Biofuel	28%
Oil	8%
Heat pumps	15%
Coal	6%
Surplus heat	7%
Electric boilers	3%
Peat	6%

In 1997, 107.2 TWh was used for heating purposes and hot water supply in dwellings (73%) and public places/premises (27%). District heating is most common in flats. *(Energimyndigheten, 1998)*

Research in the field of energy is continuos and is gaining increasing interest e.g. because of climate change. Development in the large-scale systems is leading to facilities that may be used for different kinds of fuels, learning from the lesson not to build oneself into dependence of one single fuel, preferable at the time of construction as was done with fossil fuels. Another change being increasingly utilised in technique is co-generation of heat and electricity, which is more energy-efficient.

3.1.2 Fuels – scope and data

As stated above, the selection of fuels studied here is not based solely on preferences for future fuel use. One of the primary requirements is availability of data. This makes fuels under development, such as hydrogen or solar energy with storage, unsuitable even though they may be very interesting. The use of heat pumps is also excluded to decrease complexity of calculations.

The fuels chosen are waste (household fraction), two biofuels (Salix and forest residues) and fossilgas. This selection is based on relevance of the fuels and following the exclusions mentioned above. Biofuels are assigned high preference as future fuels in Sweden and both Salix and forest residues are debated concerning land use, biodiversity, greenhouse gas emissions, etc. and is therefor interesting to include. Waste is an interesting fuel since the incineration of waste is simultaneously a process producing heat and taking care of waste. Finally, fossilgas, which has also been discussed during the last years, represents the fossil fuels. In this section these four fuels are described and limitations and scope relevant for all tools are stated (for a more thorough systems description see IVL *(1999)* and Vattenfall, *(1996)*). Exceptions and tool-specific information is described for each tool later in respective analysis presentation.

3.1.2.1 Data

Data for the case studies are taken primarily from the IVL-report ”Miljöfaktabok för bränslen” *(1999)*. They have in turn collected data from various studies (mainly LCAs or

LCIs) made in Sweden. Part of the aim of the IVL-report is to facilitate inclusion of environmental aspects in choice of fuels. The scope of these studies are varying and differences occur in emission factors concerning transport and electricity mixtures. To obtain more comprehensive inventories use of natural resources, chemicals and land, as well as emissions to water and production of waste and by-products needs in many cases further research. As the data are gathered for LCAs they are not always completely compatible with other tools. This is of course a limitation, but have also given rise to some interesting discussions.

Energy use data are presented as kWh_{fuel} or $kWh_{electricity}$, which means that the energy utilised is not followed all the way to the cradle. In a proper LCA nuclear power should be followed to the uranium ore extracted, oil back to raw oil, etc. The largest implications of this is for nuclear power, where 2/3 of the energy leaves the power plant as surplus heat and only 1/3 is turned into electricity *(Vattenfall, 1996)*. Nuclear power is only contributing to a small share of the inventory data of the fuels, but this should anyway be noticed.

All the fuels are assumed to be used in large-scale district heating facilities, 50-300 MW, where heat only is produced and the emissions data are average values of current combustion- and cleaning techniques *(IVL, 1999)*.

3.1.2.2 Salix

Salix is one of the fast growing tree species used for energy production. The first harvest is possible four to five years after plantation and then harvests may take place every three to five years over a period of 25-30 years. Harvesting can be performed in two separate ways, either the “on site splintering” or the “whole sprout” method. Using the former method results in a fuel with a moisture level of 50%, whereas in the latter the harvest is stored for half a year and the moisture level decreases to 30%. *(IVL, 1999)*

The stages contributing to the Salix inventory data include cultivation (preparation of the ground, fertiliser use and parts of the production of fertiliser), transport of harvest (30 km is assumed), combustion, and production and transport of ammonia to purify emissions *(Vattenfall, 1996; IVL, 1999)*. 80% of the harvested Salix is assumed to be splintered on site and 20% stored as whole sprouts *(IVL, 1999)*. Emissions, waste and by-products from the district heating facility are included in the inventory data, but not the construction, maintenance and deconstruction of the facility. This is assumed to be similar, independent of fuel use. Deposition or retrieval of ashes resulting from incineration is included, but separation of cadmium from the ashes and handling of the cadmium is not accounted for.

3.1.2.3 Forest residues

Forest residues are defined as consisting of branches, tops and sometimes also stubs, needles and small trees *(Zetterberg and Hansén, 1998; Kretsloppsdelegationen, 1998; IVL, 1999)*. After felling these are collected, splintered and transported (50 km is assumed) to the combustion facility. Retrieval or deposition of ashes is also included in the system under study. 50% moisture in the residues is assumed. *(IVL, 1999)*

Forest residues account for approximately 25% TS biomass of the whole tree *(Egnell et al., 1998 cited in Zetterberg and Hansén, 1998)*. This figure is an approximation, since different geographical regions and different forests provide different amounts of residues. According to Skogforsk *(G. Andersson, Skogforsk, personal communication)*, today most of the forest residues used for heat production is taken from large spruce clear-felling sites close to roads.

A report from Kretsloppsdelegationen *(1998)* estimates that forest residues theoretically could give 80 TWh and that 20-65 TWh is possible to obtain if proper environmental management is used. It states that many uncertainties regarding energy from forest residues exists, but also that this is an under-utilised energy source. An estimate is that maybe only 10 percent of the potential is utilised *(Egnell et al., 1998)*. The way the extraction of the residues is handled is of course very important in considering possible environmental impacts. Egnell et al. *(1998)* have performed an EIA (which is more of a SEA) for withdrawal of forest residues and compensation of loss of nourishment and they present several suggestions for how the forest residues may be extracted in a preferable manner.

The process creating the residues (harvesting of wood) is assumed to be performed whether the residues are to be used or not, so activities previous to the collection is allocated to the production of wood, etc.

3.1.2.4 Waste (household fraction)

Production of household waste in Sweden was 3 678 000 tonnes in 1997, out of which over 1/3 was used for producing energy from incineration. 95% of this energy was used in district heating. *(RVF, 1998)*

Handling waste as a resource rather than as a useless by-product is becoming more common. The amount of waste incinerated has doubled since 1980, and the connected energy production has increased by almost four times *(RVF, 1998)*. The twofold nature of waste gives rise to a problem when analysing the environmental impact of waste handling processes. Producing heat is not the only function of waste combustion; the process is also taking care of the waste. To consider the same system in all four fuel cases, taking care of a certain amount of waste should be included also in the three other scenarios or impacts should be allocated to respective function. This is not done in this paper, but should be kept in mind.

Another problem occurring when analysing waste processes is identifying upstream sources, where to draw the boundary. In this study waste is considered as “raw material”, and the boundary is drawn after disposal of waste from households. Previous effects of products are charged the function of that product.

The waste system in the case studies begins with the transportation of waste to the combustion facility (30 km is assumed). Waste imported or long-distance transported within Sweden has not been considered in the assumed average transport figure, probably underestimating some impacts, because of differing transport modes and longer distances *(IVL, 1999)*. Potential transportation of the waste from the household to the collecting site is not accounted for. The constitution of the combustible household waste is assumed to be 85% biotic and 15% abiotic (this is handled as oil in the calculations) *(J. Åström, Svenska Renhållningsverksföreningen, personal communication)*. Some of the IVL inventory data (Tab. 3) are specific for the waste combustion facility in Högdalen. These data are used when no Swedish average value is given.

Incentives for increased heat production from waste are the planned tax on land-filling of waste and prohibition of deposition of combustible waste *(RVF, 1998)*. These incentives will especially apply for industry waste *(RVF, 1998)*. Potentially, there will be some disagreement on burning or recycling of the combustible fraction of household waste.

3.1.2.5 Fossilgas

In Sweden, the portion of fossilgas to the total energy provision is low, 2%, this can be compared to the world average figure of approximately 25% *(Energimyndigheten, 1998)*. Methane, CH_4, is the main constituent of fossilgas. The use of fossilgas in Sweden started as late as 1985, when the most southwestern part of the country was connected to the Danish pipelines *(IVL, 1999)*. International interest for fossilgas is increasing. The advantage of fossilgas is its lower emissions as compared to other fossil fuels, but still it is a fossil fuel. If an extension of the fossilgas pipelines is decided upon, a large infrastructure investment will be made, which will have far reaching consequences.

The quality of the fossilgas in the study is assumed to be that of fossilgas from the Norwegian Ekofisk field *(Vattenfall, 1996)*. Inventory data for production and distribution in the IVL report *(1999)* are mainly based on the Vattenfall report *(1996)*. Boring and extraction, and maintenance of the platform is handled within the study. Prospecting on the other hand is not included, and neither is construction and demolition of facilities on the gas field and pipelines from Norway to Denmark. Construction of pipelines in Denmark and Sweden are included, as well as production and transports of material used for the construction and maintenance of pipelines. An allocation is made so that 20% of the interventions originating from the Danish part of the pipeline and 40% of the Swedish pipeline is included. The lifetime of the pipeline is assumed to be 40 years. Interventions originating from compression and transportation of gas are included. Transportation of waste to deposit is included and emissions from deposited material excluded. Oil and gas are extracted simultaneously and allocations of resources and emissions are done according to energy produced.

3.2 Inventory data

The inventory data obtained from the IVL-report *(1999)* are expressed per MJ_{fuel}. The conversion factor from MJ_{fuel} to usable energy, as suggested in the IVL-report, is 1.06 MJ_{heat}/MJ_{fuel} for the biofuels and waste, for fossilgas it is 1.04 MJ_{heat}/MJ_{fuel}. In the effective heating values used in the IVL-report steam is not included and that is why a degree of efficiency higher than one is possible using flue gas condensation in the heating facility.

In Table 3 the inventory data from the IVL-report together with some additional data are presented. For calculations of additional data see Appendix 1 and for area requirement and own weight see ecological footprint and MIPS calculations, respectively.

Table 3. Inventory data for the four fuels presented per MJ heat produced (E means exponent, i.e. E02 is the same as 10^2).

Inputs & outputs (per MJ heat)	**Salix**	**forest residues**	**waste**	**fossilgas**
INPUTS				
hydro (kWh_{el})	2,17E-06	-	6,13E-05	1,25E-06
biofuel excl. fuel studied (kWh_{fuel})	-	-	4,72E-06	1,25E-07
nuclear (kWh_{el})	1,79E-05	-	4,83E-05	1,06E-06
fossilgas excl. fuel studied (kWh_{fuel})	6,32E-03	-	-	4,13E-03
oil excl. fuel studied (kWh_{fuel})	6,04E-03	1,04E-02	3,41E-03	7,88E-04
coal (kWh_{fuel})	2,83E-05	-	-	9,62E-05
wood (mg)	-	-	-	1,06E-02
iron ore (mg)	-	-	-	21,2
used fuel weight (mg)	1,08E+05	1,12E+05	9,43E+04	2,02E+04
land use, field/forest (m^2*yr)	4,96E-02	0,27	-	1,85E-05
own fuel contribution, biofuel (MJ)	0,94	0,94	0,80	-
own fuel contribution, fossilgas (MJ)	-	-	-	0,96
own fuel contribution, oil (MJ)	-	-	0,14	-
OUTPUTS				
emissions to air (mg)				
NO_x	80,2	93,4	56,4	64,4
SO_x	39,7	40,3	55,8	0,22
CO	293	297	28,4	12,3
NMVOC, non-methane volatile organic compounds	21,4	22,9	1,53	2,79
CO_2	3,11E+03	2,83E+03	2,31E+04	5,85E+04
N_2O	4,72	4,72	3,77	0,53
CH_4	4,72	4,72	0,47	2,79
dust #	2,45	3,68	1,23	2,12E-02
NH_3	2,98	2,36	2,83	-
dioxins #	-	-	9,43E-06	-
HCl #	-	-	9,43	-
Hg #	-	-	0,02	-
Cd #	-	-	4,72E-04	-
Pb #	-	-	5,66E-03	-
Cu #	-	-	5,66E-02	-
Cr #	-	-	9,43E-03	-
emissions to water (mg)				
tot-N (aq)	2,55E-03	3,30E-03	-	2,50E-03
Hg #	-	-	1,13E-04	-
Pb #	-	-	1,32E-03	-
Cd #	-	-	2,64E-05	-
Cr #	-	-	2,26E-04	-
waste (mg)				
waste and by-products	1,60E+03	1,60E+03	-	17,3
waste, total	-	-	1,42E+04	-

Values for waste specific for the Högdalen incineration facility.

- No data available.

3.3 Environmental systems analysis

3.3.1 Choice of tools

Some of the tools described in chapter 2 were chosen for analysing heat produced by the different fuels. The ones written in bold below were chosen for different reasons.

- Environmental Impact Assessment (EIA)
- Strategic Environmental Assessment (SEA)
- **Life Cycle Assessment (LCA)**
- Positional Analysis (PA)
- Cost-Benefit Analysis (CBA)
- **Material Intensity Per unit Service (MIPS)**
- Total Material Requirement (TMR)
- **Ecological Footprint (EF)**
- **Exergy Analysis**
- Emergy Analysis
- Risk Assessment (RA)

EIA does not fit because the decision-situation analysed is more strategic than on project level. That is why SEA seems to be more appropriate. SEA, as described in 2.3 is performed parallel to the decision process, making out a separate part of that particular process. This makes it hard to perform a SEA within this paper. Another problem is the lack of Swedish guidelines, implying that those who use the tool also create new “standards” for how to use it. The SEA will not be performed here. LCA fits in. As it is a well-known tool and also much broader in scope than the other tools, in theory “everything” is considered, it is selected. Since PA is so broad, including other aspects than environmental, there is not enough time and knowledge at hand to try that tool. Also CBA is excluded due to the same reason. MIPS and Ecological footprints are both relevant, estimating respectively total amount of material moved and area required to support the production of heat. TMR is not, since it is focused on regional material flows. Only one of the energy analyses is tried, the exergy analysis. Obviously, RA for chemicals is not really relevant in this case.

3.3.2 LCA calculations

3.3.2.2 Goal and scope

The goal and scope of the case study is generally presented for all tools in 3.1.2. The functional unit of this LCA is 1 MJ heat produced. Intended readers would be deciding authorities and other interest groups.

3.3.2.3 Process flow charts

Salix
- Production of plant (not included)
- Preparation of ground
- Use of fertiliser/pesticides
- Harvesting (and splintering)
- Transports
- (Splintering)
- Incineration

forest residues
- Collection
- Splintering
- Transports
- Incineration

waste
- Collection of household waste
- Transportation
- Incineration

fossilgas
- Extraction
- Transportation
- Incineration

3.3.2.4 Classification

The different inputs and outputs were distributed under relevant impact categories, (Table 4). For the categories not considered any further in the quantitative case study, e.g. biotic resources, land use and biodiversity, more interventions then those selected here may be of interest, but are not presented here.

Table 4. Classification of the interventions in relevant environmental impact categories.

IMPACT CATEGORY	EMISSIONS AND EXTRACTIONS
Abiotic resources	Nuclear power Fossilgas Oil Coal Iron ore Hydropower
Biotic resources [1]	Biofuel
Land use [1]	Hydropower Biofuel Coal
Global warming	CO_2 N_2O CH_4
Depletion of stratospheric ozone	N_2O [2]
Photooxidant formation	CO NMVOC NO_x [3] CH_4
Acidification	NO_x [3] SO_x [3] NH_3 HCl [2]
Eutrophication	NO_x [3] NH_3 Tot-$N_{(aq)}$
Ecotoxicological impacts	Hg, Pb, Cd, Cu, Cr Dioxins
Biodiversity impacts [1]	Hydro power Biofuel Nuclear power Coal
Human health	Nuclear power NMVOC Dioxins
	Hg, Pb, Cd, Cu, Cr NO_x [3] SO_x [3] CO dust NH_3 CH_4
Waste	Nuclear power By-products Waste

[1] impact categories not quantitatively included in the following study.
[2] since the contribution of this substance to this category is comparably very small it is left out in the calculations (for HCl the exclusion is also caused by the fact that it is also inventoried for waste).
[3] NO_x and SO_x contribute to different impacts, they have their own taxes, which are assumed to cover these impacts and therefore the taxes are used directly for weighting and hence they are not included in the characterisations.

3.3.2.5 Characterisation and Valuation

The weighting method used here is a new method being developed *(Johansson, 1999)* and this is the first study where it is used. The valuation is based on Swedish environmental taxes and fees. The method provides one-step weighting factors, which means that the figures from the inventory table are directly multiplied with factors containing both characterisation and valuation. To obtain these one-step factors Johansson uses different characterisation methods and combines them with relevant modified taxes or fees. The descriptions of the characterisation methods following are mainly taken from Johansson *(1999)*, where more details are available.

For NO_x and SO_x emissions their respective taxes, 40 SEK/kg NO_x and SEK/kg S are used directly to weight their total impacts. Consequently the contributions of NO_x and SO_x to impact categories, e.g. acidification, eutrophication, are not part of each category's resulting value.

Abiotic resources

For this category it is important to note, again, that energy use is not followed to the "cradle" in the inventory data, meaning that nuclear power input should be approximately three times larger and the other fuels probably some percent larger due to pre-combustion activities not accounted for.

Two separate characterisation methods are used for this impact category. Finnveden and Östlund *(1997)* base their method on exergies (energy quality) of materials and energy carriers. Inventory energy data in the case study is assumed to have the same exergy as their energy content, in reality the exergy is slightly higher *(Finnveden and Östlund, 1997)* but this is assumed to have little influence on the total result. In this section the one-step weighting factors are not used, since the data were converted to exergy (MJ) separately.

Valuation is made from energy taxes, maximum (based on the 0.14 SEK/MJ tax on petrol which is not included in any environmental class) and minimum (based on non-existing electricity tax for industry). This seemed more relevant than the other tax suggested, natural gravel extraction tax, since most resource data in the study are energy carriers.

The other method, suggested by Guinée and Heijungs *(1995)*, is based on the abundance and demand for resources. Yearly extraction and the ultimate reserve are used for comparison among substances. No suitable factors for biofuels were given, neither for characterisation nor valuation and thereby only abiotic resources are considered. In this case the taxes used for the one-step weighting factors are tax on coal (max) and fossilgas tax (min).

Biotic resources

Not considered in this valuation weighting method.

Land use

Not considered in this valuation weighting method.

Global Warming

The characterisation method by IPCC *(1995)* states GWPs, Global Warming Potentials, for gases and all gases are converted into CO_2-equivalents. GWPs change over time, here values for 20, 100 and 500 years are utilised. The tax on CO_2 emissions for households is used to value global warming.

Depletion of stratospheric ozone
The exemption fee on ozone depleting substances is 600 SEK/kg independent of substance considered. Since the effect of N_2O is insignificant compared to the substances affected by this fee, and no other ozone depleting substances are emitted, no contribution to this impact category is considered in the case study.

Photo-oxidant formation
Two separate characterisation methods are used for photo-oxidant formation. Heijungs et al., *(1992, cited in Lindfors et al., 1995)* calculates characterisation factors based on respective contribution to ozone formation at peak ozone concentration. The POCPs, Photochemical Ozone Creation Potentials, are then presented as ethene-equivalents.

The method suggested by Finnveden et al. *(1992, cited in Lindfors et al., 1995)* also calculates POCPs and presents them as ethene-equivalents. Three different ways of calculating POCPs are suggested: maximum formation of ozone by the studied substance; average formation during 0-4 days with Swedish background; and average formation during 0-4 days with high NO_x background. The 73 substances presented do not include NMVOC, why this was calculated by adding 72 of the substances (excluding CO) and using the average as an estimate for NMVOC.

Characterisation factors from these two methods are combined respectively with the exemption fee for high levels of benzene in petrol. A max and a min value are obtained since the exhausts from cars with and without catalytic converters differ. This fee may not be totally relevant for this impact category since it may be decided upon mainly considering risk of cancer for humans.

Acidification
The characterisation method used for this section is suggested by Finnveden et al. *(1992, cited in Lindfors et al., 1995)*, and compares the amount of protons released in a terrestrial system. Characterised values are expressed as SO_2- equivalents and they are presented for a minimum and a maximum scenario. The sulphur tax of 30 SEK/kg S is used for valuation of acidification.

Eutrophication
Finnveden et al. *(1992, cited in Lindfors et al., 1995)* suggest a method for characterisation of eutrophication where a division between terrestrial and aquatic impacts is made. In the terrestrial sub-category only nitrogen is considered. NH_3 emissions to air in the inventory data are converted into N-equivalents. The tax on NO_x is converted to cost per kg nitrogen and used for weighting.

$$40\ [\text{SEK/kg } NO_x] = 40\ [\text{SEK/kg } NO_x]\ /\ 14\ [\text{kg N}]\ /(14+16*2)[\text{kg } NO_x] = 130\ \text{SEK/kg N}$$

In the aquatic sub-category each substance is characterised by measuring oxygen consumed when mineralising the organic material produced from it. Different circumstances give different values and the maximum oxygen demand scenario has been utilised for the one-step weighting factors. The tax on nitrogen fertilisers is used for valuation.

Ecotoxicological effects
This category is characterised by a method developed by Jolliet and Crettaz *(1997)* based on no effect concentrations (NEC). Emissions that reach their NECs over a period of one year, in the whole ecosystem under study, are considered equally toxic. The effect is assumed to be linear considering concentration and polluted volume.

Aquatic ecotoxicity potentials (AEPs) for emissions to water are valued with the general pesticides tax, here used on copper, and for emissions to air with the max and min tax on high contents of lead in petrol. Terrestrial ecotoxicity potentials (TEPs) for emissions to air are valued using the max and min fee on high contents of lead in petrol.

Emissions stated as "dioxins" in the inventory data are considered as TCDDs (2,3,7,8-tetrachlorodibenzo-p-dioxin) in the case study calculations.

Biodiversity loss
Not considered in this valuation weighting method.

Human health
There are no appropriate taxes for non-toxicological effects on human health or effects on working environment and consequently they are not considered within the valuation weighting method used here. Two characterisation methods are used for toxicological effects on human health. The method by Jolliet and Crettaz *(1997)* mentioned under ecotoxicological effects is applicable. Human toxicity potentials (HTPs) are calculated from the fraction of a toxin taken up by humans related to the non-toxic dosage of that substance. The one-step weighting factors for emissions to air consist of HTPs combined with taxes on benzene and lead. HTPs for emissions to water are combined with the pesticide tax used on copper.

The second method is suggested by the Environmental Defence Fund, EDF (1999), who has developed toxicity equivalence potentials (TEPs) based on the fraction that a human could take up after a certain amount of a substance has been emitted. The TEPs are divided in cancer and non-cancer effects. Emissions of carcinogenic substances to air are valued with the taxes on benzene and lead, as well as the general pesticide tax used on cyanazine. This pesticide tax is also used for emissions of carcinogenic substances to water. Non-carcinogenic substances are valued for air emissions with fees on benzene and lead, as well as the general pesticide tax used on malation and dianazine and for water emissions with the general pesticide tax used on malation and copper, and the tax on cadmium in phosphor fertilisers.

Waste
Waste is not characterised. A tax on landfill waste, which will come into force in 1999 is used directly as weighting factor.

3.3.2.6 Combining values

After weighting the different inputs and outputs under their respective categories a large amount of results are gained. To get more comprehensible results, one weighting process was selected where more than one had been used. Deciding on which weighting method to use is, as always, subjective.

For abiotic resources the method suggested by Finnveden and Östlund *(1997)* is chosen. Since this method is considering exergy consumed and the case study is focused on energy it seemed to be the most relevant method. The difference in result from the two methods utilised for photo-oxidant formation is considered negligible. Finnveden et al. *(1992, cited in Lindfors et al., 1995)* is selected because the span is slightly broader. Finally, for human health aspects the weighting with the characterisation by Jolliet and Crettaz *(1997)* is selected because this method produces values for all four fuels. The maximum value presented by this method makes a significant contribution to the total weighting of waste, but the max-figure using the other characterisation method would have given an even higher contribution. This is mainly because the latter includes dioxins, which Jolliet and Crettaz *(1997)* do not. The importance in the choice of characterisation method is thereby illuminated.

From each weighted impact category the maximum and minimum figures are picked, so that the whole span of results is illuminated without having to present all possible combinations of impact values. In Table 5 the final minimum and maximum values for the four fuels are presented. Results of all methods are presented in Appendix 2.

3.3.2.7 Results

In studying the resulting figures it should be kept in mind that this analysis is not complete and therefore no direct conclusions may be drawn from these results. The following discussion is based on the resulting figures in Table 5 and should not be considered as final opinions.

Comparing minimum values of environmental impact between the fuels shows differentiation between the biofuels on the one hand and waste and fossilgas on the other. What can be noted is that for the biofuels the impacts of global warming and impacts caused by NO_x are the major contributors to the final minimum value. For waste these two categories plus “waste” are dominating. Fossilgas on the other hand ends on the highest minimum value solely because of the global warming impact.

Looking at the maximum values, Waste suddenly becomes more than a hundred times worse than the biofuels, with fossilgas somewhere in between. The high total impact value of waste is caused by the toxicological impact values. The big span provided by the human health weighting is the reason for the leap in total impact and this is an interesting aspect of the life cycle impact assessment. Substances contributing the most to the high value are mercury to air, chromium to air and lead to air, in that order (Appendix 2). They are characterised highly by Jolliet and Crettaz *(1997)* and also valued highly by the benzene fee. Here the great importance of the choice of methods is really illuminated. Between the highest valuation weighting factor (based on benzene 100 SEK/kg) and the lowest (based on lead 180 SEK/kg) for a single substance there is a difference of 100 000 times! If the characterisation method suggest by EDF *(1998)* had been used instead the weighting of human health impact would have become even more outstanding and in this case totally dominated by the dioxins, which are not characterised by the former method.

Human health is in the maximum scenario the utter most important impact to be considered. Unfortunately, emissions contributing to this category is only reported for waste in the inventory database and therefor the fuels are not comparable in this field. If the impacts on human health are excluded because of this inconsistency, waste is more or less on the same level as the biofuels.

Table 5. Minimum and maximum values in SEK/MJ heat produced for the four fuels studied (E means exponent, i.e. E02 is the same as 10^2).

	Value	Value			Value	Value
SALIX	min	max		**RESIDUES**	min	max
Abiotic	0	6,3E-03		Abiotic	0	5,2E-03
Global warming	1,5E-03	1,7E-03		Global warming	1,4E-03	1,6E-03
Photo-oxidant[1]	4,8E-04	6,9E-03		Photo-oxidant[1]	5,0E-04	7,2E-03
Acidification[1]	0	8,4E-05		Acidification[1]	0	6,7E-05
Eutrophication (aq)[1]	2,9E-05	2,9E-05		Eutrophication (aq)[1]	2,3E-05	2,3E-05
Eutrophication (terr)[1]	3,2E-04	3,2E-04		Eutrophication (terr)[1]	2,5E-04	2,5E-04
Ecotoxicology	-	-		Ecotoxicology	-	-
Human health	4,1E-08	4,3E-03		Human health	4,4E-08	4,7E-03
Waste	4,0E-04	4,0E-04		Waste	4,0E-04	4,0E-04
NO_x	3,2E-03	3,2E-03		NO_x	3,7E-03	3,7E-03
SO_x	6,0E-04	6,0E-04		SO_x	6,0E-04	6,0E-04
SUM	**6,5E-03**	**2,4E-02**		SUM	**6,9E-03**	**2,4E-02**
	Value	Value			Value	Value
WASTE	min	max		**GAS**	min	max
Abiotic	0	1,8E-03		Abiotic	0	1,4E-01
Global warming	8,8E-03	9,0E-03		Global warming	2,2E-02	2,2E-02
Photo-oxidant[1]	4,2E-05	5,8E-04		Photo-oxidant[1]	3,7E-05	6,0E-04
Acidification[1]	0	8,0E-05		Acidification[1]	-	-
Eutrophication (aq)[1]	2,7E-05	2,7E-05		Eutrophication (aq)[1]	3,0E-08	3,0E-08
Eutrophication (terr)[1]	3,0E-04	3,0E-04		Eutrophication (terr)[1]	-	-
Ecotoxicology	6,4E-04	1,2E-03		Ecotoxicology	-	-
Human health	6,8E-05	7,1E+00		Human health	1,0E-08	1,1E-03
Waste	3,6E-03	3,6E-03		Waste	4,3E-06	4,3E-06
NO_x	2,3E-03	2,3E-03		NO_x	2,6E-03	2,6E-03
SO_x	8,4E-04	8,4E-04		SO_x	3,3E-06	3,3E-06
SUM	**1,7E-02**	**7,1E+00**		SUM	**2,4E-02**	**1,6E-01**

[1] NO_x and SO_x emissions are not accounted for in the photo-oxidant formation, acidification and eutrophication categories, but separately accounted for using respective tax directly.

Fossilgas is still ten times worse looking at maximum values. This is because of high influence of abiotic resource use, obtained by the extraction of the fossilgas itself. The omission of biotic resources impacts in the case study makes it difficult to compare the biofuels with the fossilgas. But it is probable that biotic resource use would have been lower valued than the abiotic. Waste has an advantage here, since it is not directly a natural resource no resource depletion is connected to its use.

The results of the characterisation step are shown in the tables in Appendix 2 and will only be shortly discussed here. Characterising abiotic resource use gives different emphasis depending on which method is used. Guinée and Heijungs *(1995)* give a low characterised value for nuclear power, this implies that not much uranium is used per kWh and the uranium reserve is not very threatened. They also value coal lower than the other fossil fuels. In the other method suggested by Finnveden and Östlund *(1997)* the focus is on exergy use and as mentioned earlier this is only based on approximate figures in this study, not presenting differences between energy sources. In the well-established method for characterising global warming

(IPCC, 1995), emissions of N_2O are given weight, but the larger amounts of CO_2 emitted still makes CO_2 the largest contributor to this impact category. When it comes to the characterisation of acidification, two scenarios are presented. With “the best soils” from this point of view NO_x and NH_3 are not contributing to acidification at all, leaving the whole impact to SO_x emissions. In the aquatic eutrophication impact sub-category NH_3 to air and tot-N to water are characterised higher than NO_x to air, this means that ammonia gives some contribution to the total, which is dominated by NO_x. The method by Jolliet and Crettaz *(1997)* is used both for toxicological impacts on ecosystem level and on human health. Characterising ecotoxicology, they emphasise the importance of emissions of mercury and cadmium and for human health emissions to air of mercury, cadmium, chromium and lead are given weight.

Summarising the result of this LCA leads to the demand for more comprehensive and covering data, particularly in the toxicological field. The importance of choosing characterisation and valuation methods must also be emphasised. This is particularly difficult also in the toxicological field, which is not really shown here because of lack of data. Finally, basing the choice of future fuel for heat production on this study is not recommended, because of the important data gaps. The impression given here is that impacts of the biofuels and waste are altogether more or less the same, with disadvantage for fossilgas (when the human health category is excluded). Impacts related to biodiversity, land use and biotic resources are not considered and they should be qualitatively described for the different fuels and added to the final result. Figures for land use may be taken from the EF calculations in 3.3.4.

3.3.3 MIPS calculations

Performing the MIPS analysis turned out to be most difficult when using a LCA-focused database. Only two of the five ecological rucksacks are usually considered in LCAs, the abiotic and biotic ones. Unfortunately this leads to an incomplete MIPS analysis where the amounts of water, soil and air disturbed by human activities are not included. It is important to keep this in mind when studying the results from this mutilated MIPS analysis.

3.3.3.1 MI- factors

The factors for calculating the MIs (material intensities) of energy and resource input are obtained from the Wuppertal Institute, partly from the Internet *(Wuppertal Institute, 1999)* partly from a publication by Manstein *(1996)*. All the MIs are hence based on German figures. Since biotic resources are not accounted for in these references, only abiotic MIs are used with the exception of own calculations of biotic resources weights. For calculations of MI-factors see Appendix 3.

MIs for hydroelectric power are defined for running water, reservoir and pump-reservoir *(Manstein, 1996)*. The reservoir figures would have been most suitable for Swedish electricity production, but these are German figures and they use reservoir hydro power only for peak supply, which gives high MIs not appropriate for Swedish hydropower *(M. Ritthoff, Wuppertal Institute, personal communication)*. Hydropower is, because of this, not included in the calculations.

The MI factor for nuclear power is for a pressure water reactor (970 MW). The figure is 266 kg/MWh and is calculated from German electricity production *(Manstein, 1996)*.

For coal production the value for imported pit coal is used, since this is assumed to be a better average for Swedish coal consumption than German domestic coal *(Wuppertal Institute, 1999).*

Calculations of the fuels' own weights:
For biofuels and waste no ecological rucksacks are included.

- **Salix**

The energy content of forest cultivated for energy is 7.9 GJ_{fuel}/ton (50% moisture) and 12.1 GJ_{fuel}/ton (30% moisture) *(Energifakta, 1994).*
$(0.8 * 7.9 + 0.2 * 12.1)*10^3$ [MJ_{fuel}/ton] = $8.74*10^3$ MJ_{fuel}/ton
$(1/8.74*10^3)$ [ton/MJ_{fuel}] / 1.06 [MJ_{heat}/MJ_{fuel}] = $1.1*10^{-4}$ ton/MJ_{heat}

- **Residues**

The energy content of forest fuels is 8.4 GJ_{fuel}/ton (50% moisture) *(Energifakta, 1994).*
$(1/8.4*10^3)$ [ton/MJ_{fuel}] / 1.06 [MJ_{heat}/MJ_{fuel}]= $1.1*10^{-4}$ ton/MJ_{heat}

- **Waste**

According to Energifakta *(1994)* household waste provide 10 GJ_{fuel}/ton.
$(1/10*10^3)$ [ton/MJ_{fuel}] / 1.06 [MJ_{heat}/MJ_{fuel}]= $0.94*10^{-4}$ ton/MJ_{heat}

- **Fossilgas** *(Wuppertal Institute, 1999).*

1.22 [ton/ton] / 41 000 [MJ/ton] / 1.04 [MJ_{heat}/MJ_{fuel}] = $2.9*10^{-4}$ ton/ MJ_{heat}

Without the rucksack the weight of fossilgas is *(Energifakta, 1994)*
38.9 [MJ/m^3] / 0.75E-3 [ton/m^3] = $52*10^3$ [MJ/ton]
$(1/52*10^3)$ [ton/MJ] / 1.04 [MJ_{heat}/MJ_{fuel}] = $1.9*10^{-5}$ ton/ MJ_{heat}

Inputs are multiplied with respective MI factor to get the total MI of each input. Weights are then divided into abiotic or biotic, and separately added. Finally abiotic and biotic MIs are aggregated to get a total weight of abiotic and biotic material intensity of 1 MJ heat produced using each type of fuel.

3.3.3.2 Results

Table 6. Results from the abiotic and biotic MIPS analysis (E means exponent, i.e. E02 is the same as 10^2).

		Impacts (ton/MJ heat)							
Inputs	Factors	**Salix**	**Salix**	**residues**	**residues**	**waste**	**waste**	**fossilgas**	**fossilgas**
(per MJ heat)	(ton/x)	(abiotic)	(biotic)	(abiotic)	(biotic)	(abiotic)	(biotic)	(abiotic)	(biotic)
biofuel (kWh fuel)	1,88E-04						8,84E-10		2,34E-11
nuclear (kWh el)	8,36E-05	1,50E-09				4,04E-09		8,84E-11	
f.gas (kWh fuel)	1,07E-04	6,77E-07						4,43E-07	
oil (kWh fuel)	1,14E-04	6,91E-07		1,19E-06		1,40E-06		9,02E-08	
coal (kWh fuel)	1,59E-03	4,49E-08						1,53E-07	
wood (mg)	1,00E-09							1,06E-11	
iron ore (mg)	1,00E-09							2,12E-08	
fuel weight (mg)	1,00E-09		1,08E-04		1,12E-04	1,42E-05	8,02E-05	2,86E-04	
	SUM:	**1,4E-06**	**1,1E-04**	**1,2E-06**	**1,1E-04**	**1,6E-05**	**8,0E-05**	**2,9E-04**	**2,3E-11**
	TOT	**1,1E-04**		**1,1E-04**		**9,6E-05**		**2,9E-04**	

The results in Table 6 show that the total weight of abiotic and biotic material affected by heat production is approximately the same for waste and the biofuels. The material intensity of producing the heat using fossilgas is almost three times larger. It is only the fossilgas calculations that include the rucksack of the fuel itself, which is of some importance since the pure gas weight is about one magnitude less. Splitting the material intensities in abiotic and biotic parts gives a more interesting view. The biofuels, of course, have a large share in the biotic part, whereas fossilgas almost explicitly affect abiotic material. If abiotic resources are considered more important to leave undisturbed, this view gives another answer than the total result. Then, the biofuels are about a hundred times “better off”.

Lack of data is a major problem in this analysis, except only looking at biotic and abiotic materials there are other gaps. Generally, the input side of the inventory table is somewhat incomplete, as chemicals used are not reported and natural resource use is mostly reported only as energy use. A more thorough inventory of inputs may give different MIPS results, but this is hard to predict since material intensities are hard to estimate.

As stated earlier, the result presented here is not the result of a full MIPS analysis. Inclusion of water, soil and air MIs could have altered the figures considerably. This is also one of the characteristics of MIPS, not many other environmental systems analyses include such impacts, and would therefore probably have contributed with interesting aspects. Manstein *(1996)* describes the material intensities of electricity and the figures for the German supply is per MWh 4 690 kg material, 83 431 kg water, and 613 kg air is affected.

3.3.4 Ecological footprint calculations

Inputs and outputs presented in the report and relevant for this analysis are: hydropower, nuclear power, CO_2 emissions, tot-$N_{(aq)}$ emissions to water. Land area directly utilised was separately calculated. The ecological footprints calculated here is the footprints of 1 MJ heat produced. The ranking of fuels obtained from their respective footprints are compared with the rankings obtained by the other methods.

This analysis has taken time into consideration and the resulting figures are stated as m^2*y/MJ_{heat}. To make this into a part of the total footprint of an average Swedish person, an approximation of the average heat consumption in MJ_{heat}/y * capita is used. This result is more similar to general footprints, since the time dimension is lost. However, in this study the footprint of 1 MJ heat is used (and anyhow the ranking is still the same).

3.3.4.1 Converting factors

Hydropower:
Wackernagel and Rees *(1996)* suggest a world average conversion factor for hydropower of 0.01 m^2/MJ/y. This estimate includes land flooded by dams and land occupied by power line corridors. As the hydropower contribution is stated in kWh in the IVL database *(1999)*, the converting factor used here will be

3.6 [MJ/kWh] * 0.01 [m^2/MJ/y] = 0.036 m^2/kWh/y

Nuclear power:
To decide how large an area energy produced by nuclear power corresponds to is not an easy task. Wackernagel *(1998)* solves this by using the area corresponding to the same amount of energy produced by fossil fuel. Wackernagel admits that many would argue that the land requirements for nuclear power are much smaller than this. Two reasons for this choice are presented firstly the effects of catastrophes (e.g. Chernobyl) leads to the loss of productive land areas and secondly he argues that nuclear power is uneconomic and the least expensive alternative for the operator is probably fossil fuels. The figure estimated is 71 GJ/ha/y *(ICLEI, 1999)* and the converting factor used here will be

$3.6*10^{-3}$ [GJ/kWh]* (1/71) [ha/GJ/y] * 10000 [m^2/ha] = 0.51 m^2/kWh/y

The fossil energy sources are accounted for as CO_2 emissions.

CO_2 emissions:
Area appropriated for fossil fuel consumption is calculated as the area of immature forest needed to assimilate the CO_2 emitted *(Wackernagel and Rees 1996).* These forests have to be left undisturbed when mature to avoid the release of sequestered carbon. On the other hand CO_2 emitted from the use of biofuels are assumed to be reabsorbed by new biofuel produced *(Wackernagel, 1998).*

According to calculations in Wackernagel *(1998)* the world average carbon absorption rate is 1.4 tonnes/ha/y. The C to CO_2 ratio is 0.2727 g CO_2-C/g CO_2.

0.2727 [mg C/mg CO_2] * ($1/1.4*10^9$) [ha/mg C/y]* 10000 [m^2/ha] = $1.95*10^9$ m^2/mg CO_2/y

tot-$N_{(aq)}$ emissions to water
Following the example of Folke et al. *(1997)* a figure for potential nitrogen retention by wetlands is used to estimate area appropriated for N-emissions to water. Consequently, an underestimation is made since N-emissions to air are not accounted for. The potential retention is, according to Jansson et al. *(1997)* 0.4 – 1.1 tonnes N/km^2/y, and the average of 0.75 N/km^2/y is used.

($1*10^{-3}$ /0.75) [m^2/mg N/y] = $1.3*10^{-3}$ m^2/mg N/y

3.3.4.2 Land area appropriated for producing fuel

Land area occupied for production of fuels is not included in the IVL database *(1999)*, why these had to be separately calculated.

Salix:

Harvest: 12 tonnes TS/ha/y *(B-M Brännström, Vattenfall, personal communication)*
Calorific value: 18.3 MJ_{fuel}/kg TS *(Energifakta, 1994)*
Heat conversion: 1.06 MJ_{heat}/MJ_{fuel} *(IVL, 1999)*

$12*10^3$ [kg TS/ha/y] * 18.3 [MJ_{fuel}/kg TS] = $220*10^3$ [MJ_{fuel}/ha/y]

(1/22) [$m^2/MJ_{fuel}/y$] / 1.06 [MJ_{heat}/MJ_{fuel}] = 0.043 [$m^2/MJ_{heat}/y$]

Forest residues:
Zetterberg and Hansén *(1998)* (using data from Egnell et al. *(1998))* estimate the energy from residues possible to extract from clear-felling sites to be 1.7 MWh/ha*y, using today's technique. Extracting from both clear-felling sites and when thinning out would increase this figure to 2.3 MWh/ha*y. These figures are not assuming 100% outtake but the practical management, which means that about 70% of the branches and tops and 30% of needles are collected. The figures are Swedish averages and only include areas where the only restrictions for extraction are of technical nature.

(1/0.17) [m^2/kWh/y] / 3.6 [MJ/kWh] / 1.06 [MJ_{heat}/MJ_{fuel}] = 1.54 [$m^2/MJ_{heat}/y$]

From this area roundwood (timber and pulpwood) is also extracted. To make an allocation of the area between roundwood and forest residues a very approximate average figure for forest residues biomass as a share of the total biomass is used. The residues constitute about 25% of the total biomass from the tree *(Zetterberg and Hansén, 1998 based on Egnell et al., 1998).* Allocation of the forest area then gives a final figure of

1.54 [$m^2/MJ_{heat}/y$] * 0.25 = 0.385 [$m^2/MJ_{heat}/y$]

Waste:
No area is included for the "production" of waste.

Fossilgas:
Area for gas pipelines = $1.33*10^{-4}$ [$m^2/kWh_{el}/y$] *(Vattenfall, 1996)*
Area for extraction of gas and related transports = $8.09*10^{-5}$ [m^2/kWh_{el}] *(Vattenfall, 1996)*

The area requirement for extraction is not related to time. Since it is hard to assume how many years to split the extraction figure between this figure is excluded from further calculations. This is not assumed to be relevant for the total outcome because of the low area claim.

Since the figure is related to kWh_{el} produced, converting calculations need to be made. The degree of efficiency is 53% *(Vattenfall, 1996).*

$1.33*10^{-4}$ [$m^2/kWh_{el}/y$] * 0.53 [kWh_{el}/kWh_{fuel}] / 3.6 [MJ/kWh] /1.06 [MJ_{heat}/MJ_{fuel}]
= $0.18*10^{-4}$ [$m^2/MJ_{heat}/y$]

The above converting factors are multiplied with respective inventory data to gain areas appropriated. All the area parts of each fuel are added together. Potential overlapping is assumed to be of little importance since two of the area shares are totally dominating. Since they are net CO_2 emissions and area for producing the fuel they can not be the same.

To obtain an approximation of the contribution of heat consumption to an average Swedish person's ecological footprint an approximation of heating required per person is calculated using data from Energimyndigheten *(1998)*.

Energy for heating (1997) = 107.2 TWh
Part of this used in dwellings = 73%
Population = $8.8*10^6$

107.2 [TWh] $*3.6*10^9$ [MJ/TWh]* 0.73 / $8.8*10^6$ [cap] = $3*10^4$ MJ/cap

3.3.4.3 Results

Table 7 shows that CO_2-emissions and direct land use clearly make up the major part of the total heat production footprint. Since direct land use is not a big issue for fossilgas or waste the area appropriated by using these fuels more or less equals the area needed for CO_2 assimilation. The biofuels on the other hand have large production area requirements. For Salix cultivation this is a well-known impact, but the allocation made between forest residues and roundwood is questionable. The underlying data is uncertain and besides, share of biomass may not be the best allocation ground in this case. Another possibility would have been to allocate the whole area to roundwood production, since the residues are a by-product. This would have decreased the footprint for residues burning substantially. Then forest residues would have been the most preferable fuel under study from the shoe size perspective.

Table 7. Results from the ecological footprint analysis (E means exponent, i.e. E02 is the same as 10^2)

Inputs and outputs (per MJ heat)	Factors (m^2/x/yr)	**Salix** (m^2*yr/MJ heat)	**residues** (m^2*yr/MJ heat)	**waste** (m^2*yr/MJ heat)	**fossilgas** (m^2*yr/MJ heat)
hydro (kWh el)	3,60E-02	7,81E-08		2,21E-06	4,50E-08
nuclear (kWh el)	5,07E-01	9,09E-06		2,45E-05	5,36E-07
fossilgas (kWh fuel)	3,87E-01				
oil (kWh fuel)	5,07E-01				
coal (kWh fuel)	6,55E-01				
land use field/forest (m^2*yr)		4,96E-02	3,85E-01		1,85E-05
CO2 (mg)	1,95E-06	6,06E-03	5,51E-03	4,50E-02	1,14E-01
tot-N (aq) (mg)	1,33E-03	3,40E-06	4,40E-06		3,33E-06
	SUM:	**5,6E-02**	**3,9E-01**	**4,5E-02**	**1,1E-01**
footprint per capita for heat consumption	(m^2/capita)	**1,7E+03**	**1,2E+04**	**1,4E+03**	**3,4E+03**

To summarise the results of the footprint analysis, a more thorough analysis would have to be made to achieve a trustworthy result. The difference in area appropriated by the heat production is almost one magnitude. The footprint of waste resulting from this study is one of the two smallest. This can be further supported by the fact that waste incineration is providing a second function, taking care of waste. On the other hand the "production" of this fuel is not included, but may be considered of less importance.

3.3.5 Exergy calculations

The exergy analysis is a bit incompletely performed. It is important to note, again, that energy use is not followed to the "cradle" in the inventory data, meaning that nuclear power input should be approximately three times larger and the other fuels probably some percent larger due to pre-combustion activities not accounted for. Additionally the energy is not equal to the exergy amount as assumed here. The exergy should be somewhat larger *(Finnveden and Östlund, 1997)*.

3.3.5.1 Converting factors

For all energy carriers the energy content is assumed to be equal to the exergy content. For 1MJ heat produced the conversion factors (1.04 MJ_{heat}/MJ_{fuel} for fossilgas and 1.06 MJ_{heat}/MJ_{fuel} for the other fuels) are used to get the energy used to produce 1 MJ heat *(IVL, 1999)*.

$$1\ MJ_{heat} / 1.06\ MJ_{heat}/MJ_{fuel} = 0.94\ MJ_{fuel}$$

The only other input considered is iron ore, which has the chemical exergy of 0.42 MJ/kg *(Finnveden and Östlund, 1997)*.

In splitting the exergies in abiotic and biotic sources, hydropower is defined as abiotic. Describing the categories as renewable and non-renewable would instead have placed hydropower on the “good” side, as a renewable resource. Since this localisation is not relevant for the result of the analysis it is not further discussed here.

3.3.5.2 Result

Table 8. Results from the exergy analysis (E means exponent, i.e. E02 is the same as 10^2).

		Impacts, MJ/MJ heat							
Inputs	Factors	**Salix**	**Salix**	**residues**	**residues**	**waste**	**waste**	**fossilgas**	**fossilgas**
(per MJ heat)	(MJ/x)	(abiotic)	(biotic)	(abiotic)	(biotic)	(abiotic)	(biotic)	(abiotic)	(biotic)
hydro (kWh el)	3,6	7,81E-06				2,21E-04		4,50E-06	
biofuel (kWh fuel)	3,6						1,70E-05		4,50E-07
nuclear (kWh el)	3,6	6,45E-05				1,74E-04		3,81E-06	
fossilgas (kWh fuel)	3,6	2,28E-02						1,49E-02	
oil (kWh fuel)	3,6	2,17E-02		3,74E-02		4,42E-02		2,84E-03	
coal (kWh fuel)	3,6	1,02E-04						3,46E-04	
iron ore (mg)	4,20E-07							8,88E-06	
energy of fuel			9,43E-01		9,43E-01	1,42E-01	8,02E-01	9,62E-01	
	SUM:	**4,5E-02**	**9,4E-01**	**3,7E-02**	**9,4E-01**	**1,9E-01**	**8,0E-01**	**9,8E-01**	**4,5E-07**
	TOT :	**9,9E-01**		**9,8E-01**		**9,9E-01**		**9,8E-01**	

Data in Table 8 show that the energy content of the fuel itself is the outstanding exergy contributor. Since the study is on heat production, this may not be very controversial. However, filling the data gaps considering resource inputs may give some additional interesting exergy sources. The advantage of splitting the results in abiotic and biotic exergy sources is illuminated. As mentioned in the MIPS analysis, this makes it possible to see aspects that may be important if biotic resources are considered to be less “dangerous” to use/deplete.

It can be noted that, in this case, an energy analysis would have given the same result as this exergy analysis did. The only difference is the exergy of iron ore.

3.4 Summary and discussion of the case study results

Comparing the results of the case study illuminates some differences and similarities. In Table 9 the rankings of the fuels obtained from the analyses are presented. The size of the difference in between ranking numbers vary and may sometimes be small, which must be kept in mind. Also it should be noted that the ranking is based on the results based on inventory data not fully comparable and with data gaps and should not be considered as recommendations or final figures.

Table 9. Summarising the rankings of the fuels obtained from the analyses, 1=best to 4=worst. It should be noted that the differences in impact between the fuels may be large or small and that this is not made seen in this table. It should further be noted that the table is based on the results of the analyses, not considering inconsistencies in data and data gaps discussed in respective result section.

tool	Salix	residues	waste	fossilgas
LCA				
abiotic	2	1	2	4
global warming	1	1	3	4
[photo-oxidant] [1]	3	3	1	1
[acidification] [1]	2	1	2	-
[eutrophication (aq)] [1]	2	2	2	1
[eutrophication (terr)] [1]	*	*	*	-
ecotoxicological	-	-	*	-
human health #	2	2	4 #	1
waste	2	2	4	1
NO_x	*	*	*	*
SO_x	2	2	4	1
total, min ¤	1	1	3	4
total, max ¤	1	1	1	4
MIPS				
abiotic	1	1	3	4
biotic	3	3	2	1
total	x	x	x	x
EF	1	4	1	3
Exergy analysis				
abiotic	1	1	3	4
biotic	3	3	2	1
total	*	*	*	*

[1] NO_x and SO_x emissions data are not included in the acidification and eutrophication categories, but separately accounted for.
- no data available.
* no significant difference can be seen.
# the human health category includes more emissions for waste than for the other fuels and provides an unfair ranking.
¤ in the total ranking the human health and ecotoxicological categories are excluded because of the inconsistency in inventories.
x inconsistency in data and small differences makes ranking impossible

For all the studies it should be noted that waste is providing more than one function. The environmental burdens accounted for are related both to heat production and waste care

Both exergy analysis and MIPS analysis results may be presented as abiotic and biotic share of the total. For exergy no significant difference can be interpreted from the total result and for MIPS the differences are very small. Splitting the data in abiotic and biotic parts provides the same ranking from both methods. Focusing on the abiotic share gives fossilgas followed by waste a disadvantage and consequently biofuels have the largest influence in the biotic sector. This is easily explained since the fuels´ own weights and exergy contents are dominating. Both exergy and MIPS analysis look at the inputs to the system only and they emphasise the burdens caused by use and depletion of natural resources, emissions are not considered. But if a full MIPS had been performed, including air, soil and water affected, a different result would maybe have turned out.

LCA is the only tool used here that includes toxicological aspects. LCA is most of all disfavouring fossilgas, when looking at the total results excluding impact categories affected by unequal system boundaries for the fuels (ecotoxicology and human health). Looking at the ranking of LCA within the different impact categories it is interesting to note that fossilgas is only ranked lowest in two cases, abiotic resources and global warming. It is also ranked highest in several categories. In the case of eutrophication this is however due to the lack of NH_3 emissions data for fossilgas. Looking at this more transparent result presentation it can be seen which categories are weighted as more important than the others. It would have been useful to use and compare different valuation methods as well, to illuminate possible differences in the total ranking.

It can be concluded that the MIPS and exergy analyses give the same ranking of fuels. Assuming that the depletion of abiotic resources is weighted more heavily than biotic resources, biofuels are considered the best choice followed by waste and fossilgas. The LCA total ranking follows the same pattern, but does not part biofuels and waste. This difference can be explained by the fact that in the LCA waste has been considered a “free resource” since use of waste can not be described as use/depletion of abiotic and biotic resources. Using the other two methods weight and exergy content of waste is included, thereby assigning waste a larger environmental burden.

The ecological footprint ranking stands out from the others and puts forest residues as a worst choice, followed by fossilgas. In this case study the EF is totally focusing on CO_2 emissions and area appropriated for producing the fuel. This gives waste a favourable position, since no ”production-area” is associated with this fuel. Forest residues are given a large direct land use area, which is discussed in 3.3.4.

An important aspect arising from the case study is that transparency of the results presentation is utterly meaningful. Only stating the final figures resulting from these analyses would not have been of any use at all. Reasoning about why the appropriated area is larger for one fuel than the other is and about what impact is weighted highest and why, is important. For this reason LCA may be credited since it includes thorough reporting stating impact categories separately and making results transparent.

4. DISCUSSION AND CONCLUSIONS

Comparing the eleven tools described in 2.2 to 2.12 reveals some similarities and differences. It is important to note that all tools are not intended to cover the same areas. It must be underlined that PA and CBA are economical tools incorporating environmental aspects. The others are environmentally focused and should be combined with other tools in order to give decision makers social, economical and maybe also technical inputs, as well as environmental, to support a practicable decision. Some tools may be more useful in some situations, depending on complexity and cost of the method as well as on the preferences of the performer. What issue is the most important is a very subjective question and the tools in this study differ in focus and scope. In the following discussion some of the aspects separating and uniting them will be described. First of all the tools are defined as considering only natural resource use or direct environmental impacts or both. The objectives of the analyses are described as PPPPs (projects, plans, programmes and policies), economies/populations, products /functions and chemicals.

4.1 Natural resource use

Five of the tools concentrate on natural resource use rather than on environmental impacts (Fig. 5), which may be seen as an indirect way of getting at the latter. These tools are the energy analyses (exergy and emergy), the material flow analyses (TMR and MIPS) and the EF. Even though the EF is a bit in the periphery, trying to convert some emissions into the natural resource "productive area" needed to take care of that emission.

One main similarity of these five tools discussed here is that toxicological aspects are left unconsidered and environmental impacts are not directly addressed. These methods take the easy way out and sometimes a complementing analysis of toxicological effects is suggested. Another similarity is that they all avoid actual weighting to obtain one single unit. Some sort of valuation is on the other hand made in choosing to look at energy, weight or area as an indicator of environmental burden. An advantage of this approach is that currently "popular" environmental problems are not highlighted and problems not yet discovered get the same attention or rather in-attention.

Exergy and emergy analyses put the focus on energy but in separate ways. The first emphasise the importance of the amount of energy quality used and is thereby very much a tool for maximising efficiency. The second includes the input from nature, going all the way back to the energy from the sun, the tide and the geological earth heat. Exergy analysis is the physicist's or the engineer's tool and emergy the systems ecologist's to describe the tools focusing on origin. They are broad tools, applicable for economies/populations, products and projects. Both appear to be rather difficult to interpret and they are so far not very often practised for environmental management. More pedagogic are the other three tools of this group. The two material flow analyses appear to be more or less the same method, only applied on different objects, TMR on economies and MIPS analysis on services. TMR is partly based on the MIPS concept, which may be an example of the terminology jungle in the field of environmental systems analytical tools (the proper name for the MIPS analysis should be MAIA, material intensity analysis). Another difference between them is that the TMR is not including air and water mass affected by human activities, but this is more out of practical reasons and those aspects may well be included when data are more easily obtained. EF handles the natural resource "ecologically productive surface area" and contrary to the four other tools in this "group" includes area needed to take care of emissions (so far mostly CO_2). The footprint idea of presenting the world's need for more globes to sustain our current living is very effective and pedagogic. However, uncertainties are large and the conclusions that may be drawn from the case study is that EF is probably, in its current form, more appropriate for economies and populations than for activities and products. It may also be convenient for complementary studies, since land use is not often regarded. EF is also one of the few tools practically handling the question of biodiversity. A share of the globally available productive area is set aside for other species. Further development to make the size of this share more substantiated is ongoing. Emergy analysis, since developed by an ecologist, also tries to handle this complex issue by measuring the emergy needed to produce the genetic information compared to the energy of the energy carrier, which would be the gene. Other difficult issues are population growth and equity aspects, which are parts of some of the tools' foundations. For comparison of footprints the globally available ecologically productive space is divided equally among the world's citizens and an increased population is directly visible in decreased available ha per capita figures. This is not directly seen in the footprint analysis, but when performing it on a per capita basis this comparison is often made. The MIPS and TMR analyses intends to illuminate the fact that importing countries have part of the responsibility of the environmental burdens created in the exporting country. This is illustrating the dependence of many industrialised economies on resources imported from developing countries. In emergy analysis wealth as defined today is not considered to be the "true wealth" ("true wealth" is produced and maintained by work processes from the environment, sometimes supported by man) and the Emergy Sustainability Index applied on economies is inversely proportional to "economic development status" *(Brown and Ugliati, 1997).*

The energy analyses may be described as scientific tools and this may give credibility but also a sense of complexity. MIPS, TMR and EF may be considered to be based on more idealistic grounds and to not be truly scientific. This can be a disadvantage when presented in more strict, conservative circles. The message provided by these tools is the same, our current lifestyles are not sustainable and major changes need to be made. MIPS, TMR and EF provide broader results and do not intend to give exact answers. In many situations methods like these may be for comparably quick reviews, e.g. screening-LCAs as mentioned in the description of MIPS. It may also be dangerous to always focus on details, since we do not have all-covering knowledge. In developing the emergy analysis, some of these idealistic thoughts are put into a more scientific surrounding.

4.2 Environmental impacts

"RA for chemicals" is the only tool in this study that does not consider the effects of natural resource use. It looks at environmental impacts and focuses on the adverse effects of chemicals (Fig. 5), mostly on humans. RA is an outsider in this paper and will show more relevant similarities with the others as it is slowly starting to be applied on environmental issues. In the form presented here, it is only used where actual danger is feared for, since it is quite costly and time consuming.

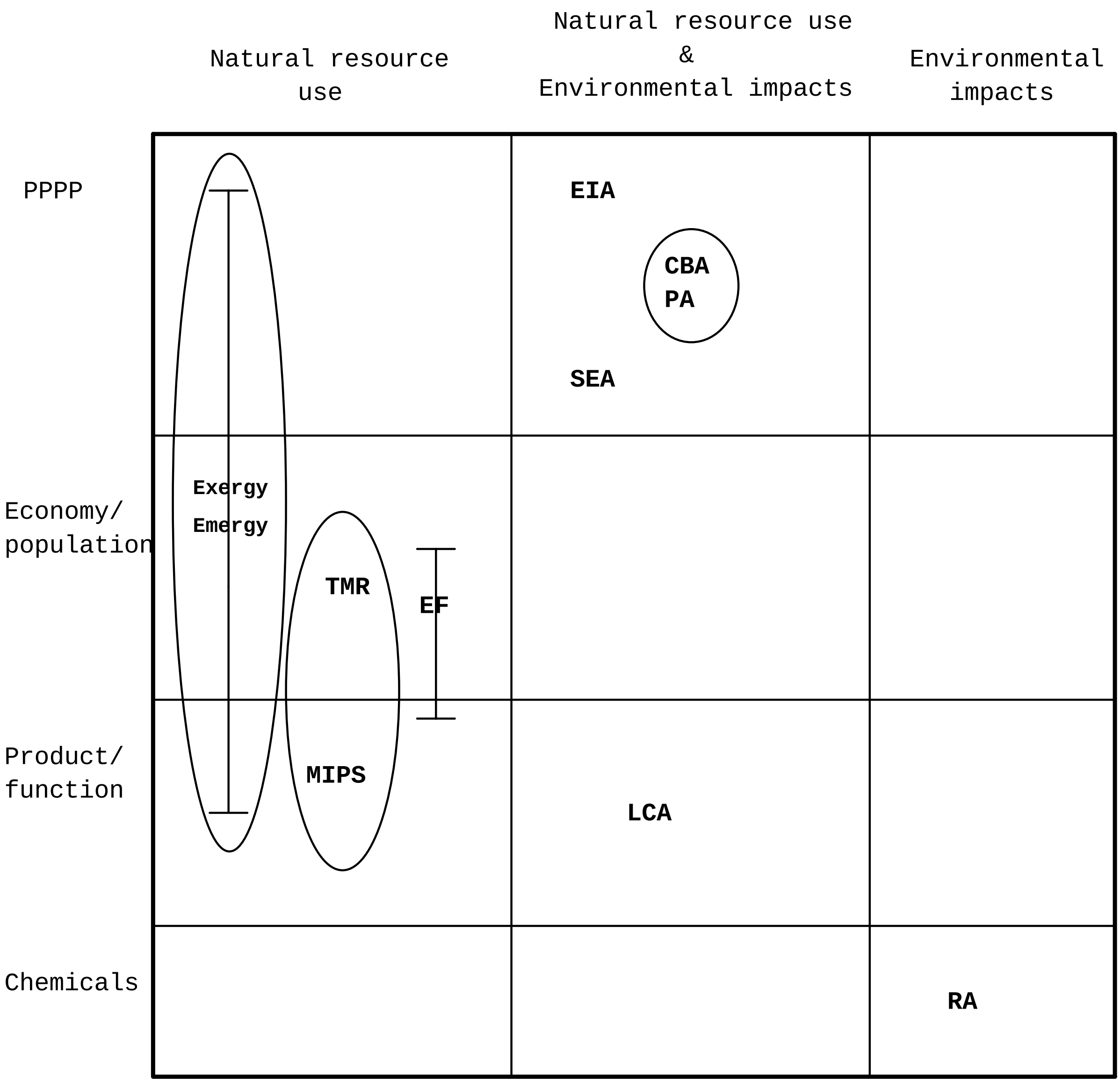

Figure 5. Schematic distribution of the eleven tools considered in this report. The encircled areas are the groups, from left to right, energy analyses, material flow analyses and economical analyses. The dotted line marks the potential for this group if other material flow tools had been studied. PPPP = policies, plans, programmes and projects.

4.3 Natural resource use <u>and</u> environmental impacts

The five remaining tools (EIA, SEA, LCA, PA and CBA) include both environmental impacts and natural resource use in their analyses (Fig. 5). Toxicological aspects are also theoretically included. Uncertainty is however large in the toxicological field, there are gaps in our knowledge and the toxicological field is very broad. To include these impacts <u>in theory</u> is not good enough and it is of great importance to observe what is really analysed and how. Sometimes it may feel as more harm is done including problematic issues and doing it badly, than not including them at all. But, it is important to develop and increase our knowledge and toxicological aspects can most certainly not be left out of environmental management.

EIA, CBA and PA are the most site-specific of the tools considered in this paper and they are all mainly used to evaluate projects and sometimes plans. SEA, handling policies, programme and plans, need to be region specific, depending on what decision level that is considered. There is a discussion going on concerning the development of LCA, trying to make this tool more site-dependent. It can never become site-specific, however, since the exact time and place of e.g. emissions are not known. This is a consequence of the fact that LCA is product or function related, whereas the others are effect related. LCA considers potential impacts and not actual effects in nature.

A problem facing all attempts to analyse total environmental impacts is weighting the impacts to each other. This is always a subjective process and will consequently always be debated. It may be questioned whether weighting is necessary, but in a decision situation some kind of valuation at some stage is unavoidable. As mentioned above, some tools have solved this problem by performing the analysis directly in one unit (kg, J, m^2). LCA and CBA perform direct valuations. For LCA this is not compulsory and even when a valuation is made all the steps, not only the results of the valuation are interpreted to obtain a final recommendation. CBA usually base the valuations on preferences of individuals affected, which may not be seen as a trustworthy approach. Some objections may be that people are divided into category groups assumed to have the same opinions, questions may be asked in different ways and there is no reason to assume that what a person prefer is best from a broader perspective. Because of subjectivness of valuation among other things, it is very important to present transparent documents. When the result is presented in an aggregated form as in CBA and sometimes LCA this is of utmost importance, since it is easy to simply be satisfied with the yes/no answer presented and forget about assumptions and weightings made to reach this answer. In guidelines and the ISO-standardisation of LCA this is emphasised. Results from the other analyses are presented differently, more or less aggregated or disaggregated. One of the characteristics of PA is that it leaves the valuation as much as possible to the actual decision-maker. In SEA and EIA no single aggregated figure have to be presented, but to decide on a recommendation valuations are still made.

4.4 Usability

If the tools are considered from the users point of view, their usability is differing. If the objective of study is a product or a function, then LCA, MIPS, exergy or emergy analysis are relevant and LCA is the only of these directly handling environmental impacts. It is a well-established tool and it is developed to be used by companies. The last statement may however lead to questions concerning subjectiveness. Some of the others are not at all constructed mainly for company use. They are not as complete as LCAs, but can still not be considered to be fit within the LCA territory. MIPS analysis provides another boundary between the ecosystem and the technical system within, accounting for all the disturbance human activities cause. This may indirectly illuminate more long-term potential impacts. Emergy analysis also sets a different boundary by going all the way back to the earth’s primary energy sources (the sun, the tide and the earth heat). Using this approach also, at least theoretically, facilitates the inclusion of labour, knowledge and biodiversity issues by the use of transformities and emergy/GDP ratios, as described in 2.11. Exergy analysis may be used to achieve a more efficient production process. The two energy analyses may feel complicated and people may consider energy units abstract, which would make these methods less pedagogic while mass in tonnes is more easily comprehensible. Using MIPS may be pedagogic but currently not easy. This is due to the lack of complete and comprehensible guidelines, but also because data may be hard to get since the scope of a MIPS is broader than for most of the more established approaches. LCA is standardised and is getting well established, on the other hand it must be carefully used and thoroughly interpreted. Performance is time-consuming and using the result should at least consume some time. LCA is a method developed for products and functions explicitly and it gives the most detailed result if well performed.

Decisions regarding the four Ps, projects, plans, programmes and policies may be supported by planning tools like EIA, CBA, PA or SEA. The first three are mainly used for planned projects (development actions) and sometimes also to evaluate possible consequences of plans. Differences are obvious since EIA is only handling environmental issues, whereas CBA and PA are economical tools including environmental aspects. It may be considered positive or negative to gather different aspects in on method versus performing specific analyses for each and then make final evaluations with information from them all. PA is developed as a more transparent alternative to CBA, leaving more choices and consequently more work to the decision-maker. It also illuminates conflicting opinions and possible irreversible impacts. As EIA is not developed to analyse higher level strategic decisions, such as plans, programmes and policies a rather new tool has been introduced to fill the gap, the SEA. This tool, so far, has rather vague guidelines both internationally and domestically but as it is being more practically used the framework will slowly be built. It is important to include environmental aspects already at early stages in strategic decisions and SEA is therefor a positive contribution to the toolbox. Emergy and exergy analysis may also theoretically be used for PPPPs, but are not frequently practised. EIA-use is requested by law in many cases and CBA is often used by companies and authorities. PA is more of a theoretical tool maybe too time consuming and broad for most analysts. Guidelines are published and since the developer is Swedish extra support may be achievable. Since it is a very new tool, SEA is so far not very frequently performed. Interest is however growing and the more studies performed the easier to practice and develop the tool. In some cases these planning tools may be seen as frameworks wherein many individual choices of internal methods have to be made. CHAINET *(1998)* makes a difference between e.g. EIA and LCA defining the former as a procedural tool focusing on procedures to guide the best way to the decision and the latter as an analytical tool using computational algorithms or checklists to reach the better decision. EIA may be described as a framework and within this framework different analyses are performed. This can also be said about LCA with the difference that LCA has a more or less LCA-specific box of methods to choose between. Choices of methods are critical for the outcome of the analysis. To place LCA on level with for example MIPS or exergy analysis it may be relevant to present the analysis as a LCA including characterisation by X and weighting by Y.

Tillman et al. *(1997)* compare the use of EIA and LCA in case studies of waste water systems. This is an example where EIA is used on the planning level analysing which waste water system is the most advantageous. The LCA is used on the same decision situation by analysing the function “the treatment of the waste water from one person equivalent during one year”. By modifying the question this situation is both project and function related. Tillman et al. concludes that a combination of the tools would be preferable to get the local aspects provided by the EIA and also the global perspective better described by a LCA.

When focus of the investigation is on an economy or a population, the relevant tools of this study are all members of the natural resource group (TMR, EF, emergy and exergy analysis). Resource use may be easier to consider in analysing an economy because of available statistics. TMR, exergy and emergy analyses may be considered more straight forward, but EF more descriptive. Probable high degree of uncertainty in these methods may not constitute a large problem, since studies of economies/populations are not performed to support detail decisions, but rather to see trends or e.g. to confirm unsustainability. TMR has not been widely used and this may constitute a problem for practitioners, lacking best practice advice on avoiding mistakes.

Finally, for decisions where dangerous substances are involved a RA for chemicals need to be performed. This is a way of deciding if the risk is worth taking, setting an acceptable level of negative effect caused by the substance in question.

4.5 Integration

As stated in SETAC *(1997)* no single approach is able to address all problems connected to environmental management. In some situations it may be sufficient to use one tool anyway, being aware of its shortages, yet in other cases it may be suitable to use two or more tools complementary. LCA proponents may present their analysis as all-inclusive and "The Tool". This may well be the intention, but all the same some parts of the lifecycle impacts are harder to include than others. Most often this is handled by simply omitting difficult impact categories. Even if this is transparently stated within the report, omission probably means decreased attention to the impact concerned. In short reviews of the LCA result it may be totally forgotten. In these cases complementing tools are welcome. Ecological footprints may give a hint of land requirement, performing a whole analysis or picking relevant parts. MIPS and emergy analysis may also give information on parts of resource use not often covered within a LCA. Exergy analysis may sometimes even be used as a characterisation of abiotic resource impacts in a LCA, as in the case study of this thesis.

All tools need complementation if the fuller picture is sought. EIA, SEA, PA and CBA are all focusing on projects, plans, programmes or policies. This gives a certain level of detail, which it is possible to go into. However, some substances involved or maybe functions produced within these Ps need a more thorough investigation. In the former case a RA may be performed and in the latter a LCA, an EF or both may be appropriate. Using any tool not directly considering environmental impacts, a complementing analysis of toxicological effects is useful. For example if a MIPS analysis is used to evaluate impacts of wheat production toxicological impacts of e.g. fertilisers and pesticides may be complementary analysed. If a LCA is chosen as complement, considering impact categories where the MIPS analysis do not give sufficient information may be preferred. Depending on opinion this may be toxicological categories or everything on the output side. Since it is preferable to get different views and broader scope it may be an advantage to use more than one tool. It may even be preferable to pick bits and pieces from different tools. Complementing use is not completely unproblematic, but could be facilitated by greater integration of tools of differing origin. Suggestions in SETAC *(1997)* are describing the benefits of integrating development and use of different tools. One of the larger benefits of this would be to decrease the effort put into inventorying, simultaneously improving the quality of the data and obtaining faster development of treatment of data. Unnecessary work developing new tools or extending existing methods could be avoided by co-operation with developers and practitioners of other tools already focusing on these issues.

One lesson of the case study is that a LCA database is not sufficient when performing a MIPS analysis and sometimes not an EF either. Practitioners of major environmental systems analysis tools know what data are needed, in many cases these are the same independent of tool. Adding the few extras to achieve a multi-tool database, as suggested by SETAC *(1997)*, seems to be an effective effort to make. Then, for each decision situation, area appropriated, material disturbed, toxicological aspects, etc. could be separately presented and compared. Except for making combination of tools easier this would also reduce uncertainty arising from the use of separate databases. A list of possible weighting methods could be provided to simplify choices and increase transparency.

4.6 Conclusions

Conclusions of this thesis are that using environmental tools illuminates the fact that no analysis will cover the whole environmental field in a sensible way. Neither will it ever be possible to provide decision-makers with a one true answer. Still, environmental systems analysis tools serve a purpose as guidance and scanning, presenting the one single figure is not the goal. Integration of concepts and tools with the overall same aim would facilitate data handling, development, harmonisation of terminology and the combination of tools. Co-operation and complementation is the solution here as in so many other situations.

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APPENDIX 1

Calculations of inventory data

Own fuel input

The input of the fuel itself to get 1 MJ of heat had to be added. For the two biofuels the calculations of fuel input were identical.

$1\ [MJ_{heat}] / 1.06\ [MJ_{heat}/MJ_{fuel}] = 0.94\ MJ_{fuel}/MJ_{heat}$

The same calculation was done for fossilgas, but using the relevant heat ratio 1.04 MJ_{heat}/MJ_{fuel}

When it comes to waste, the input was divided between biofuel and oil for the exergy analysis. An approximate division would be 15% on based on oil and 85% based on biofuel*(J. Åström, Svensk Avfallshantering, personal communication)*. The fuel input for waste is then respectively,

$0.15 * 1\ [MJ_{heat}] / 1.06\ [MJ_{heat}/MJ_{fuel}] = 0.14\ MJ_{fuel}/ MJ_{heat}$

$0.85 * 1\ [MJ_{heat}] / 1.06\ [MJ_{heat}/MJ_{fuel}] = 0.80\ MJ_{fuel}/ MJ_{heat}$

These data for waste were not used in the LCA, since it would have been accounted for as direct resource extractions (oil and biofuel), which is not the case for waste. This means that the waste input is not included at all for LCA. For MIPS the weight of the waste is accounted for without ecological rucksack (see 3.3.3). In EF the energy input of waste itself is not accounted for, but the CO_2 emissions.

Energy input, waste inventory

For waste, input figures in the IVL-database were reported using different categories than the other fuels under consideration. Some calculations had to be done to convert these figures. The figure reported for electricity use, 0.00045 MJ/MJ_{fuel}, was split up into hydropower, biofuel, nuclear power and oil. The production of Swedish electricity was separated into energy sources *(Vattenfall, 1996)*.

Hydro power	52%	Biofuel power	4%
Nuclear power	41%	Fossil fuel power (ass. oil)	3%

The thermal energy use, 0.013 MJ/MJ_{fuel}, presented in the IVL-report was assumed to be mainly oil.

<u>Hydro power:</u>
$4.5*10^{-4}\ [MJ/MJ_{fuel}] / 1.06\ [MJ_{heat}/MJ_{fuel}] * 0.52 / 3.6\ [MJ/kWh] = 6.1*10^{-5}\ kWh/ MJ_{heat}$
<u>Biofuel:</u>
$4.5*10^{-4}\ [MJ/MJ_{fuel}] / 1.06\ [MJ_{heat}/MJ_{fuel}] * 0.04 / 3.6\ [MJ/kWh] = 4.7*10^{-6}\ kWh_{fuel}/ MJ_{heat}$
<u>Nuclear power:</u>
$4.5*10^{-4}\ [MJ/MJ_{fuel}] / 1.06\ [MJ_{heat}/MJ_{fuel}] * 0.41 / 3.6\ [MJ/kWh] = 4.8*10^{-5}\ kWh/ MJ_{heat}$
<u>Oil:</u>
$(4.5*10^{-4} * 0.03 + 0.013)\ [MJ/MJ_{fuel}] / 1.06\ [MJ_{heat}/MJ_{fuel}] / 3.6\ [MJ/kWh] = 3.4*10^{-3}\ kWh/ MJ_{heat}$

APPENDIX 2

Calculation sheets for the LCA case study, presenting the characterisation and weighting steps. For each impact category the relevant emissions are characterised and also weighted using one-step weightingfactors obtained from Johansson *(1999)*. Both the characterised figures and the final values presented in the tables are used in the interpretation of the LCA result. For a short explanation of characterisation, valuation and weighting see 2.4 Life Cycle Assessment.

Explanation to abbreviations for valuations:

180 Pb	minimum fee on high contents of lead in petrol, 180 SEK/kg
350 Pb	maximum fee on high contents of lead in petrol, 350 SEK /kg
10 B	exemption fee for high levels of benzene in petrol, 10 SEK /kg
100 B	exemption fee for high levels of benzene in petrol, 100 SEK /kg
cad	fertiliser tax of 20 SEK /kg applied on cadmium
copper	fertiliser tax of 20 SEK /kg applied on copper
cyan	fertiliser tax of 20 SEK /kg applied on cyanazine
diazinon	fertiliser tax of 20 SEK /kg applied on diazinon
malation	fertiliser tax of 20 SEK /kg applied on malation
N	tax on nitrogen in fertilisers, 12 SEK /kg N leached
NO_2	tax on NO_x, 40 SEK /kg
S	tax on sulphur, 30 SEK /kg

Notes:

x	no data or characterisation factor available
*	valued by directly using the relevant tax (NO_2 or S)

ABIOTIC RESOURCES, Method of characterisation: Finnveden and Östlund, 1997

	In/Output	**Salix**	Charac. factor	Characterised (MJ)	One-step weighting factors[1] (kr/MJ) min	(kr/MJ) max	Value, min (SEK)	Value, max (SEK)
dep.	nuclear (kWh_{el})	1,79E-05	3,6	6,45E-05	0	0,14	0	9,03E-06
	fossilgas (kWh_{fuel})	6,32E-03	3,6	2,28E-02	0	0,14	0	3,19E-03
	oil (kWh_{fuel})	6,04E-03	3,6	2,17E-02	0	0,14	0	3,04E-03
	coal (kWh_{fuel})	2,83E-05	3,6	1,02E-04	0	0,14	0	1,43E-05
	iron ore (mg)	x						
flow	hydro (kWh_{el})	2,17E-06	3,6	7,81E-06	0	0,14	0	1,09E-06
							0	**6,3E-03**

	In/Output	**Residues**	Charac. factor	Characterised (MJ)	One-step weighting factors[1] (kr/MJ) min	(kr/MJ) max	Value, min (SEK)	Value, max (SEK)
dep.	nuclear (kWh_{el})	x						
	fossilgas (kWh_{fuel})	x						
	oil (kWh_{fuel})	1,04E-02	3,6	3,74E-02	0	0,14	0	5,23E-03
	coal (kWh_{fuel})	x						
	iron ore (mg)	x						
flow	hydro (kWh_{el})	x						
							0	**5,2E-03**

	In/Output	**Waste**	Charac. factor	Characterised (MJ)	One-step weighting factors[1] (kr/MJ) min	(kr/MJ) max	Value, min (SEK)	Value, max (SEK)
dep.	nuclear (kWh_{el})	4,83E-05	3,6	1,74E-04	0	0,14	0	2,44E-05
	fossilgas (kWh_{fuel})	x						
	oil (kWh_{fuel})	3,41E-03	3,6	1,23E-02	0	0,14	0	1,72E-03
	coal (kWh_{fuel})	x						
	iron ore (mg)	x						
flow	hydro (kWh_{el})	6,13E-05	3,6	2,21E-04	0	0,14	0	3,09E-05
							0	**1,8E-03**

	In/Output	**Fossilgas**	Charac. factor	Characterised (MJ)	One-step weighting factors[1] (kr/MJ) min	(kr/MJ) max	Value, min (SEK)	Value, max (SEK)
dep.	nuclear (kWh_{el})	1,06E-06	3,6	3,81E-06	0	0,14	0	5,33E-07
	fossilgas (kWh_{fuel})	4,13E-03	3,6	1,49E-02	0	0,14	0	2,08E-03
	oil (kWh_{fuel})	7,88E-04	3,6	2,84E-03	0	0,14	0	3,97E-04
	coal (kWh_{fuel})	9,62E-05	3,6	3,46E-04	0	0,14	0	4,85E-05
	iron ore (mg)	2,12E+01	4,2E-07	8,88E-06	0	0,14	0	1,24E-06
	fuel (MJ)	9,43E-01	1	9,43E-01	0	0,14	0	1,32E-01
flow	hydro (kWh_{el})	1,25E-06	3,6	4,50E-06	0	0,14	0	6,30E-07
							0	**1,3E-01**

1) the minimum value is based on non-existing electricity tax for industries (0 SEK/MJ), and
the maximum values is based on the tax on petrol not included in any environmental class
x) no data available

To use the characterisation method by Guinée and Heijungs *(1995)* all energy sources where converted into kgs.

<u>Nuclear power</u>:
1.24g (2.2% U) gives 1kWh electricity *(Vattenfall, 1996)*.
$0.022 * 1.24*10^{-3}$ [kg/kWh$_{el}$]= $0.027*10^{-3}$ kg/kWh$_{el}$

<u>Fossilgas</u>:
Density: 0.75 kg/m^3 *(Energifakta)*
Energy content: 38.84 MJ/m^3 *(Guinée and Heijung, 1995)*
0.75 [kg/m^3] / 38.84 [MJ$_{fuel}$/m^3] * 3.6 [MJ/kWh] = 0.07 kg/ kWh$_{fuel}$

<u>Oil</u>:
Energy content: 41.87 MJ/kg *(Guinée and Heijung, 1995)*
3.6 [MJ/kWh] / 41.87 [MJ$_{fuel}$/kg] = 0.086 kg/ kWh$_{fuel}$

<u>Coal</u>:
Energy content: 27.91MJ/kg *(Guinée and Heijung, 1995)*
3.6 [MJ/kWh] / 27.91 [MJ$_{fuel}$/kg] = 0.13 kg/ kWh$_{fuel}$

ABIOTIC RESOURCES, Method of characterisation: Guinée and Heijungs, 1995

continued, ABIOTIC RESOURCES, Method of characterisation: Guinée and Heijungs, 1995

	In/Output	**Salix**	(kg)	Charac. factors (ADP)	Characterised (kg)	In/Output	One-step weighting factors[1] (SEK/kg) min	(SEK/kg) max	Value, min (SEK)	Value, max (SEK)
deposit	nuclear (kWh_{el})	1,79E-05	4,89E-10	2,87E-03	1,40E-12	nuclear (kWh_{el})	2,16E-03	1,51E-01	1,06E-12	7,38E-11
	fossilgas (kWh_{fuel})	6,32E-03	4,39E-04	3,20E-01	1,41E-04	fossilgas (kWh_{fuel})	2,24E+00	1,69E+01	9,84E-04	7,43E-03
	oil (kWh_{fuel})	6,04E-03	5,19E-04	4,36E-01	2,26E-04	oil (kWh_{fuel})	3,05E+00	2,30E+01	1,59E-03	1,19E-02
	coal (kWh_{fuel})	2,83E-05	3,65E-06	6,00E-03	2,19E-08	coal (kWh_{fuel})	4,20E-02	3,16E-01	1,53E-07	1,15E-06
	iron ore (kg)	x				iron ore (kg)				
									2,6E-03	**1,9E-02**

	In/Output	**Residues**	(kg)	Charac. factors (ADP)	Characterised (kg)	In/Output	One-step weighting factors[1] (SEK/kg) min	(SEK/kg) max	Value, min (SEK)	Value, max (SEK)
deposit	nuclear (kWh_{el})	x				nuclear (kWh_{el})				
	fossilgas (kWh_{fuel})	x				fossilgas (kWh_{fuel})				
	oil (kWh_{fuel})	1,04E-02	8,92E-04	4,36E-01	3,89E-04	oil (kWh_{fuel})	3,05E+00	2,30E+01	2,72E-03	2,05E-02
	coal (kWh_{fuel})	x				coal (kWh_{fuel})				
	iron ore (kg)	x				iron ore (kg)				
									2,7E-03	**2,1E-02**

	In/Output	**Waste**	(kg)	Charac. factors (ADP)	Characterised (kg)	In/Output	One-step weighting factors[1] (SEK/kg) min	(SEK/kg) max	Value, min (SEK)	Value, max (SEK)
deposit	nuclear (kWh_{el})	4,83E-05	1,32E-09	2,87E-03	3,79E-12	nuclear (kWh_{el})	2,16E-03	1,51E-01	2,85E-12	1,99E-10
	fossilgas (kWh_{fuel})	x				fossilgas (kWh_{fuel})				
	oil (kWh_{fuel})	3,41E-03	2,93E-04	4,36E-01	1,28E-04	oil (kWh_{fuel})	3,05E+00	2,30E+01	8,95E-04	6,74E-03
	coal (kWh_{fuel})	x				coal (kWh_{fuel})				
	iron ore (kg)	x				iron ore (kg)				
									9,0E-04	**6,7E-03**

	In/Output	**Fossilgas**	(kg)	Charac. factors (ADP)	Characterised (kg)	In/Output	One-step weighting factors[1] (SEK/kg) min	(SEK/kg) max	Value, min (SEK)	Value, max (SEK)
deposit	nuclear (kWh_{el})	1,06E-06	2,89E-11	2,87E-03	8,28E-14	nuclear (kWh_{el})	2,16E-03	1,51E-01	6,23E-14	4,36E-12
	fossilgas (kWh_{fuel})	4,13E-03	2,87E-04	3,20E-01	9,19E-05	fossilgas (kWh_{fuel})	2,24E+00	1,69E+01	6,43E-04	4,85E-03
	oil (kWh_{fuel})	7,88E-04	6,78E-05	4,36E-01	2,96E-05	oil (kWh_{fuel})	3,05E+00	2,30E+01	2,07E-04	1,56E-03
	coal (kWh_{fuel})	9,62E-05	1,24E-05	6,00E-03	7,44E-08	coal (kWh_{fuel})	4,20E-02	3,16E-01	5,21E-07	3,92E-06
	iron ore (kg)	2,12E-05	9,95E-06	8,43E-08	8,39E-13	iron ore (kg)	5,89E-07	4,44E-06	5,86E-12	4,42E-11
	fuel (MJ)	9,43E-01	1,82E-02	3,20E-01	5,83E-03	fuel (MJ)	2,24E+00	1,69E+01	4,08E-02	3,08E-01
									4,2E-02	**3,1E-01**

x) no data available

1) the minimum value is based on the energy tax on coal (0.316 SEK/kg), the maximum value on energy tax on fossilgas (0.241 SEK/m^3) converted by 0.75 kg/m^3 for fossilgas (Energifakta, 1994)

GLOBAL WARMING, Method of characterisation: IPCC, 1995

In/Output	**Salix**	Characterisation factors (20 y, GWP)	(100 y, GWP)	(500 y, GWP)	Characterised (20 y, GWP)	Characterised (100 y, GWP)	Characterised (500 y, GWP)	In/Output
CO_2 (kg)	3,11E-03	1	1	1	3,11E-03	3,11E-03	3,11E-03	CO_2 (kg)
N_2O (kg)	4,72E-06	280	310	170	1,32E-03	1,46E-03	8,02E-04	N_2O (kg)
CH_4 (kg)	4,72E-06	56	21	6,5	2,64E-04	9,91E-05	3,07E-05	CH_4 (kg)

In/Output	**Residues**	Characterisation factors (20 y, GWP)	(100 y, GWP)	(500 y, GWP)	Characterised (20 y, GWP)	Characterised (100 y, GWP)	Characterised (500 y, GWP)	In/Output
CO_2 (kg)	2,83E-03	1	1	1	2,83E-03	2,83E-03	2,83E-03	CO_2 (kg)
N_2O (kg)	4,72E-06	280	310	170	1,32E-03	1,46E-03	8,02E-04	N_2O (kg)
CH_4 (kg)	4,72E-06	56	21	6,5	2,64E-04	9,91E-05	3,07E-05	CH_4 (kg)

In/Output	**Waste**	Characterisation factors (20 y, GWP)	(100 y, GWP)	(500 y, GWP)	Characterised (20 y, GWP)	Characterised (100 y, GWP)	Characterised (500 y, GWP)	In/Output
CO_2 (kg)	2,31E-02	1	1	1	2,31E-02	2,31E-02	2,31E-02	CO_2 (kg)
N_2O (kg)	3,77E-06	280	310	170	1,06E-03	1,17E-03	6,42E-04	N_2O (kg)
CH_4 (kg)	4,72E-07	56	21	6,5	2,64E-05	9,91E-06	3,07E-06	CH_4 (kg)

In/Output	**Fossilgas**	Characterisation factors (20 y, GWP)	(100 y, GWP)	(500 y, GWP)	Characterised (20 y, GWP)	Characterised (100 y, GWP)	Characterised (500 y, GWP)	In/Output
CO_2 (kg)	5,85E-02	1	1	1	5,85E-02	5,85E-02	5,85E-02	CO_2 (kg)
N_2O (kg)	5,34E-07	280	310	170	1,49E-04	1,65E-04	9,07E-05	N_2O (kg)
CH_4 (kg)	2,79E-06	56	21	6,5	1,56E-04	5,86E-05	1,81E-05	CH_4 (kg)

continued, GLOBAL WARMING, Method of characterisation: IPCC, 1995

One-step weighting factors			Value, 20y	Value, 100y	Value, 500y
20 y (SEK/kg)	100 y (SEK/kg)	500 y (SEK/kg)	(SEK)	(SEK)	(SEK)
0,37	0,37	0,37	1,15E-03	1,15E-03	1,15E-03
103,6	114,7	62,9	4,89E-04	5,41E-04	2,97E-04
20,72	7,77	2,405	9,77E-05	3,67E-05	1,13E-05
			1,7E-03	**1,7E-03**	**1,5E-03**

One-step weighting factors			Value, 20y	Value, 100y	Value, 500y
20 y (SEK/kg)	100 y (SEK/kg)	500 y (SEK/kg)	(SEK)	(SEK)	(SEK)
0,37	0,37	0,37	1,05E-03	1,05E-03	1,05E-03
103,6	114,7	62,9	4,89E-04	5,41E-04	2,97E-04
20,72	7,77	2,405	9,77E-05	3,67E-05	1,13E-05
			1,6E-03	**1,6E-03**	**1,4E-03**

One-step weighting factors			Value, 20y	Value, 100y	Value, 500y
20 y (SEK/kg)	100 y (SEK/kg)	500 y (SEK/kg)	(SEK)	(SEK)	(SEK)
0,37	0,37	0,37	8,55E-03	8,55E-03	8,55E-03
103,6	114,7	62,9	3,91E-04	4,33E-04	2,37E-04
20,72	7,77	2,405	9,77E-06	3,67E-06	1,13E-06
			9,0E-03	**9,0E-03**	**8,8E-03**

One-step weighting factors			Value, 20y	Value, 100y	Value, 500y
20 y (SEK/kg)	100 y (SEK/kg)	500 y (SEK/kg)	(SEK)	(SEK)	(SEK)
0,37	0,37	0,37	2,16E-02	2,16E-02	2,16E-02
103,6	114,7	62,9	5,53E-05	6,12E-05	3,36E-05
20,72	7,77	2,405	5,78E-05	2,17E-05	6,71E-06
			2,2E-02	**2,2E-02**	**2,2E-02**

PHOTO-OXIDANT FORMATION, Method of characterisation:
Finnveden et al., 1992 (cited in Lindfors et al., 1995)

		Characterisation factors			Characterised		
In/Output	**Salix**	max formation	average	high NO_x	max formation	average	high NO_x
CO (kg)	2,93E-04	3,60E-02	4,00E-02	3,20E-02	1,06E-05	1,17E-05	9,39E-06
NMVOC (kg)	2,14E-05	5,25E-01	3,50E-01	5,14E-01	1,13E-05	7,48E-06	1,10E-05
NO_x (kg)	8,02E-05	x	x	x			
CH_4 (kg)	4,72E-06	x	x	x			

		Characterisation factors			Characterised		
In/Output	**Residues**	max formation	average	high NO_x	max formation	average	high NO_x
CO (kg)	2,97E-04	3,60E-02	4,00E-02	3,20E-02	1,07E-05	1,19E-05	9,51E-06
NMVOC (kg)	2,29E-05	5,25E-01	3,50E-01	5,14E-01	1,20E-05	8,01E-06	1,18E-05
NO_x (kg)	9,34E-05	x	x	x			
CH_4 (kg)	4,72E-06	x	x	x			

		Characterisation factors			Characterised		
In/Output	**Waste**	max formation	average	high NO_x	max formation	average	high NO_x
CO (kg)	2,84E-05	3,60E-02	4,00E-02	3,20E-02	1,02E-06	1,14E-06	9,09E-07
NMVOC (kg)	1,53E-06	5,25E-01	3,50E-01	5,14E-01	8,03E-07	5,34E-07	7,85E-07
NO_x (kg)	5,64E-05	x	x	x			
CH_4 (kg)	4,72E-07	x	x	x			

		Characterisation factors			Characterised		
In/Output	**Fossilgas**	max formation	average	high NO_x	max formation	average	high NO_x
CO (kg)	1,23E-05	3,60E-02	4,00E-02	3,20E-02	4,43E-07	4,92E-07	3,94E-07
NMVOC (kg)	2,79E-06	5,25E-01	3,50E-01	5,14E-01	1,47E-06	9,75E-07	1,43E-06
NO_x (kg)	6,44E-05	x	x	x			
CH_4 (kg)	2,79E-06	x	x	x			

x no characterisation factor available

continued, PHOTO-OXIDANT FORMATION, Method of characterisation:
Finnveden et al., 1992 (cited in Lindfors et al., 1995)

	One-step weighting factors[1]					
In/Output	max formation min (SEK/kg)	max formation max (SEK/kg)	average min (SEK/kg)	average max (SEK/kg)	high NO_x min (SEK/kg)	high NO_x max (SEK/kg)
CO (kg)	1,14E+00	1,14E+01	1	9,95	1,01	10,06
NMVOC (kg)	1,66E+01	1,66E+02	8,69	86,95	16,156	161,562
NO_x (kg)	*	*	*	*	*	*
CH_4 (kg)						

	One-step weighting factors[1]					
In/Output	max formation min (SEK/kg)	max formation max (SEK/kg)	average min (SEK/kg)	average max (SEK/kg)	high NO_x min (SEK/kg)	high NO_x max (SEK/kg)
CO (kg)	1,14E+00	1,14E+01	1	9,95	1,01	10,06
NMVOC (kg)	1,66E+01	1,66E+02	8,69	86,95	16,156	161,562
NO_x (kg)	*	*	*	*	*	*
CH_4 (kg)						

	One-step weighting factors[1]					
In/Output	max formation min (SEK/kg)	max formation max (SEK/kg)	average min (SEK/kg)	average max (SEK/kg)	high NO_x min (SEK/kg)	high NO_x max (SEK/kg)
CO (kg)	1,14E+00	1,14E+01	1	9,95	1,01	10,06
NMVOC (kg)	1,66E+01	1,66E+02	8,69	86,95	16,156	161,562
NO_x (kg)	*	*	*	*	*	*
CH_4 (kg)						

	One-step weighting factors[1]					
In/Output	max formation min (SEK/kg)	max formation max (SEK/kg)	average min (SEK/kg)	average max (SEK/kg)	high NO_x min (SEK/kg)	high NO_x max (SEK/kg)
CO (kg)	1,14E+00	1,14E+01	1	9,95	1,01	10,06
NMVOC (kg)	1,66E+01	1,66E+02	8,69	86,95	16,156	161,562
NO_x (kg)	*	*	*	*	*	*
CH_4 (kg)						

1) the minimum and maximum valuations are based on the two benzene fees
* NO_x is not accounted for in this category, but valued directly by using the NO_2 tax

continued, PHOTO-OXIDANT FORMATION, Method of characterisation: Finnveden et al., 1992 (cited in Lindfors et al., 1995)

In/Output	Value, min max formation (SEK)	Value, max max formation (SEK)	Value, min average (SEK)	Value, max average (SEK)	Value, min high Nox (SEK)	Value, max high Nox (SEK)
CO (kg)	3,34E-04	3,33E-03	2,93E-04	2,92E-03	2,96E-04	2,95E-03
NMVOC (kg)	3,55E-04	3,55E-03	1,86E-04	1,86E-03	3,46E-04	3,46E-03
NO_x (kg)	*	*	*	*	*	*
CH_4 (kg)						
	6,9E-04	**6,9E-03**	**4,8E-04**	**4,8E-03**	**6,4E-04**	**6,4E-03**

In/Output	Value, min max formation (SEK)	Value, max max formation (SEK)	Value, min average (SEK)	Value, max average (SEK)	Value, min high Nox (SEK)	Value, max high Nox (SEK)
CO (kg)	3,39E-04	3,38E-03	2,97E-04	2,96E-03	3,00E-04	2,99E-03
NMVOC (kg)	3,80E-04	3,80E-03	1,99E-04	1,99E-03	3,70E-04	3,70E-03
NO_x (kg)	*	*	*	*	*	*
CH_4 (kg)						
	7,2E-04	**7,2E-03**	**5,0E-04**	**5,0E-03**	**6,7E-04**	**6,7E-03**

In/Output	Value, min max formation (SEK)	Value, max max formation (SEK)	Value, min average (SEK)	Value, max average (SEK)	Value, min high Nox (SEK)	Value, max high Nox (SEK)
CO (kg)	3,24E-05	3,23E-04	2,84E-05	2,83E-04	2,87E-05	2,86E-04
NMVOC (kg)	2,53E-05	2,53E-04	1,33E-05	1,33E-04	2,47E-05	2,47E-04
NO_x (kg)	*	*	*	*	*	*
CH_4 (kg)						
	5,8E-05	**5,8E-04**	**4,2E-05**	**4,2E-04**	**5,3E-05**	**5,3E-04**

In/Output	Value, min max formation (SEK)	Value, max max formation (SEK)	Value, min average (SEK)	Value, max average (SEK)	Value, min high Nox (SEK)	Value, max high Nox (SEK)
CO (kg)	1,40E-05	1,40E-04	1,23E-05	1,22E-04	1,24E-05	1,24E-04
NMVOC (kg)	4,62E-05	4,62E-04	2,42E-05	2,42E-04	4,51E-05	4,51E-04
NO_x (kg)	*	*	*	*	*	*
CH_4 (kg)						
	6,0E-05	**6,0E-04**	**3,7E-05**	**3,6E-04**	**5,7E-05**	**5,7E-04**

PHOTO-OXIDANT FORMATION, Method of characterisation:Heijungs et al., 1992 (cited in Lindfors et al., 1995)

In/Output	**Salix**	Charac. factors POCP	Charact. (kg)	One-step weighting factors[1] min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
CO (kg)	2,93E-04	x					
NMVOC (kg)	2,14E-05	4,16E-01	8,91E-06	22,01	220,11	4,71E-04	4,71E-03
NO_x (kg)	8,02E-05	x		*	*	*	*
CH_4 (kg)	4,72E-06	7,00E-03	3,30E-08	0,37	3,7	1,75E-06	1,75E-05
						4,7E-04	**4,7E-03**

In/Output	**Residues**	Charac. factors POCP	Charact. (kg)	One-step weighting factors[1] min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
CO (kg)	2,97E-04	x					
NMVOC (kg)	2,29E-05	4,16E-01	9,54E-06	22,01	220,11	5,05E-04	5,05E-03
NO_x (kg)	9,34E-05	x		*	*	*	*
CH_4 (kg)	4,72E-06	7,00E-03	3,30E-08	0,37	3,7	1,75E-06	1,75E-05
						5,1E-04	**5,1E-03**

In/Output	**Waste**	Charac. factors POCP	Charact. (kg)	One-step weighting factors[1] min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
CO (kg)	2,84E-05	x					
NMVOC (kg)	1,53E-06	4,16E-01	6,36E-07	22,01	220,11	3,36E-05	3,36E-04
NO_x (kg)	5,64E-05	x		*	*	*	*
CH_4 (kg)	4,72E-07	7,00E-03	3,30E-09	0,37	3,7	1,75E-07	1,75E-06
						3,4E-05	**3,4E-04**

In/Output	**Fossilgas**	Charac. factors POCP	Charact. (kg)	One-step weighting factors[1] min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
CO (kg)	1,23E-05	x					
NMVOC (kg)	2,79E-06	4,16E-01	1,16E-06	22,01	220,11	6,14E-05	6,14E-04
NO_x (kg)	6,44E-05	x		*	*	*	*
CH_4 (kg)	2,79E-06	7,00E-03	1,95E-08	0,37	3,7	1,03E-06	1,03E-05
						6,2E-05	**6,2E-04**

1) the minimum and maximum valuations are based on the two benzene fees

*) NO_x is not accounted for in this category, but valued directly by using the NO_2 tax.

x) no characterisation factor available

ACIDIFICATION, Method of characterisation: Finnveden et al., 1992 (cited in Lindfors et al., 1995)

In/Output	**Salix**	Charac. factors min	Characterised[1] min(kg SO_2ekv)	Charac. factors max	Characterised[1] max(kg SO_2ekv)	One-step weighting factors[1] S min (SEK/kg)	S max (SEK/kg)	Value, min S (SEK)	Value, max S (SEK)
NO_x (kg)	8,02E-05	0	0	0,7	5,61E-05	*	*	*	*
SO_x (kg)	3,97E-05	1	3,97E-05	1	3,97E-05	*	*	*	*
NH_3 (kg)	2,98E-06	0	0	1,88	5,60E-06	0	2,82E+01	0	8,41E-05
								0	**8,4E-05**

In/Output	**Residues**	Charac. factors min	Characterised[1] min(kg SO_2ekv)	Charac. factors max	Characterised[1] max(kg SO_2ekv)	One-step weighting factors[1] S min (SEK/kg)	S max (SEK/kg)	Value, min S (SEK)	Value, max S (SEK)
NO_x (kg)	9,34E-05	0	0	0,7	6,54E-05	*	*	*	*
SO_x (kg)	4,03E-05	1	4,03E-05	1	4,03E-05	*	*	*	*
NH_3 (kg)	2,36E-06	0	0	1,88	4,43E-06	0	2,82E+01	0	6,65E-05
								0	**6,7E-05**

In/Output	**Waste**	Charac. factors min	Characterised[1] min(kg SO_2ekv)	Charac. factors max	Characterised[1] max(kg SO_2ekv)	One-step weighting factors[1] S min (SEK/kg)	S max (SEK/kg)	Value, min S (SEK)	Value, max S (SEK)
NO_x (kg)	5,64E-05	0	0	0,7	3,95E-05	*	*	*	*
SO_x (kg)	5,58E-05	1	5,58E-05	1	5,58E-05	*	*	*	*
NH_3 (kg)	2,83E-06	0	0	1,88	5,32E-06	0	2,82E+01	0	7,98E-05
								0	**8,0E-05**

In/Output	**Fossilgas**	Charac. factors min	Characterised[1] min(kg SO_2ekv)	Charac. factors max	Characterised[1] max(kg SO_2ekv)	One-step weighting factors[1] S min (SEK/kg)	S max (SEK/kg)	Value, min S (SEK)	Value, max S (SEK)
NO_x (kg)	6,44E-05	0	0	0,7	4,51E-05	*	*	*	*
SO_x (kg)	2,21E-07	1	2,21E-07	1	2,21E-07	*	*	*	*
NH_3 (kg)	x								

1) the minimum and maximum are based on minimum and maximum scenarios for acidification as presented by Finnveden et al., *(1992)* .

* NOx and SO_x are not accounted for in this category, but valued directly by using the NO_2 and S taxes.

x no data available

EUTROPHICATION (aquatic), Method of characterisation:
Finnveden et al. 1992 (cited in Lindfors et al., 1995)

	In/Output	**Salix**	Charac.factor (kg O_2/kg)	Characterised (kg O_2)	One-step weighting factor N (SEK/kg)	Value N (SEK)
air	NO_x (kg)	8,02E-05	6,00E+00	4,81E-04		*
	NH_3 (kg)	2,98E-06	1,60E+01	4,77E-05	9,6	2,86E-05
water	tot-N (kg)	2,55E-09	2,00E+01	5,09E-08	12	3,06E-08
						2,9E-05
	In/Output	**Residues**	Charac.factor (kg O_2/kg)	Characterised (kg O_2)	One-step weighting factor N (SEK/kg)	Value N (SEK)
air	NO_x (kg)	9,34E-05	6,00E+00	5,60E-04	*	*
	NH_3 (kg)	2,36E-06	1,60E+01	3,77E-05	9,6	2,26E-05
water	tot-N (kg)	3,30E-09	2,00E+01	6,60E-08	12	3,96E-08
						2,3E-05
	In/Output	**Waste**	Charac.factor (kg O_2/kg)	Characterised (kg O_2)	One-step weighting factor N (SEK/kg)	Value N (SEK)
air	NO_x (kg)	5,64E-05	6,00E+00	3,38E-04	*	*
	NH_3 (kg)	2,83E-06	1,60E+01	4,53E-05	9,6	2,72E-05
water	tot-N (kg)	x				
						2,7E-05
	In/Output	**Fossilgas**	Charac.factor (kg O_2/kg)	Characterised (kg O_2)	One-step weighting factor N (SEK/kg)	Value N (SEK)
air	NO_x (kg)	6,44E-05	6,00E+00	3,87E-04	*	*
	NH_3 (kg)	x				
water	tot-N (kg)	2,50E-09	2,00E+01	5,00E-08	12	3,00E-08
						3,0E-08

*) NO_x is not accounted for in this category, but valued directly by using the NO_2 tax.
x) no data available

EUTROPHICATION (terrestrial), No characterisation

	In/Output	**Salix**	Valuation weighting factor (SEK/kg)	Value (SEK)
air	NO_x (kg)	*		
	NH_3 (kg)	2,98E-06		
	Tot-N	2,46E-06	130	**3,2E-04**

	In/Output	**Residues**	Valuation weighting factor (SEK/kg)	Value (SEK)
air	NO_x (kg)	*		
	NH_3 (kg)	2,36E-06		
	Tot-N	1,94E-06	130	**2,5E-04**

	In/Output	**Waste**	Valuation weighting factor (SEK/kg)	Value (SEK)
air	NO_x (kg)	*		
	NH_3 (kg)	2,83E-06		
	Tot-N	2,33E-06	130	**3,0E-04**

	In/Output	**Fossilgas**
air	NO_x (kg)	*
	NH_3 (kg)	x

*) NO_x is not accounted for in this category, but valued directly by using the NO_2 tax.
x) no data available

ECOTOXICOLOGICAL IMPACTS, Method of characterisation: Jolliet and Crettaz, 1997

			Charac.	Characterised	One-step weighting factors (SEK/kg)		
	In/Output	**Waste**	factors	(kg)	copper	180 Pb	350 Pb
aquatic systems	Hg (kg), to air	1,70E-08	1,96E+02	3,33E-06		2,76E+04	5,36E+04
	Hg (kg), to water	1,13E-10	1,30E+03	1,47E-07	5,00E+03		
	Pb (kg), to air	5,66E-09	1,28E+00	7,24E-09		1,80E+02	3,50E+02
	Pb (kg), to water	1,32E-09	5,20E+00	6,86E-09	2,00E+01		
	Cu (kg), to air	5,66E-08	6,60E-01	3,74E-08		9,28E+01	1,80E+02
	Cd (kg), to air	4,72E-10	7,90E+01	3,73E-08		1,11E+04	2,16E+04
	Cd (kg), to water	2,64E-11	5,20E+02	1,37E-08	2,00E+03		
	Cr (kg), to air	9,43E-09	3,90E-01	3,68E-09		5,48E+01	1,07E+02
	Cr (kg), to water	2,26E-10	2,60E+00	5,88E-10	1,00E+01		
terrestrial systems	Hg (kg), to air	1,70E-08	5,94E+00	1,01E-07		8,22E+03	1,60E+04
	Cd (kg), to air	4,72E-10	3,14E+00	1,48E-09		4,35E+03	8,45E+03
	Pb (kg), to air	5,66E-09	1,30E-01	7,36E-10		1,80E+02	3,50E+02
	Cu (kg), to air	5,66E-08	1,40E-01	7,92E-09		1,94E+02	3,77E+02
	Cr (kg), to air	9,43E-09	8,00E-02	7,54E-10		1,11E+02	2,15E+02
	Dioxins (kg), to air	9,43E-12	x				

x) no characterisation factor available

continued, ECOTOXICOLOGICAL IMPACTS, Method of characterisation: Jolliet and Crettaz, 1997

In/Output	One-step weighting factors min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
Hg (kg), to air	2,76E+04	5,36E+04	4,69E-04	9,11E-04
Hg (kg), to water	5,00E+03	5,00E+03	5,65E-07	5,65E-07
Pb (kg), to air	1,80E+02	3,50E+02	1,02E-06	1,98E-06
Pb (kg), to water	2,00E+01	2,00E+01	2,64E-08	2,64E-08
Cu (kg), to air	9,28E+01	1,80E+02	5,25E-06	1,02E-05
Cd (kg), to air	1,11E+04	2,16E+04	5,24E-06	1,02E-05
Cd (kg), to water	2,00E+03	2,00E+03	5,28E-08	5,28E-08
Cr (kg), to air	5,48E+01	1,07E+02	5,17E-07	1,01E-06
Cr (kg), to water	1,00E+01	1,00E+01	2,26E-09	2,26E-09
Hg (kg), to air	8,22E+03	1,60E+04	1,40E-04	2,72E-04
Cd (kg), to air	4,35E+03	8,45E+03	2,05E-06	3,99E-06
Pb (kg), to air	1,80E+02	3,50E+02	1,02E-06	1,98E-06
Cu (kg), to air	1,94E+02	3,77E+02	1,10E-05	2,13E-05
Cr (kg), to air	1,11E+02	2,15E+02	1,05E-06	2,03E-06
Dioxins (kg), to air				
			6,4E-04	**1,2E-03**

HUMAN HEALTH, Method of characterisation: Jolliet and Crettaz, 1997

	In/Output	**Salix**	Charac. factors	Characterised
toxicological impacts	NO_x (kg), to air	8,02E-05	2,00E-03	1,60E-07
	SO_x (kg), to air	3,97E-05	7,50E-03	2,98E-07
	CO (kg), to air	2,93E-04	1,40E-04	4,11E-08
	dust (kg), to air	2,45E-06	7,50E-03	1,84E-08

	In/Output	**Residues**	Charac. factors	Characterised
toxicological impacts	NO_x (kg), to air	9,34E-05	2,00E-03	1,87E-07
	SO_x (kg), to air	4,03E-05	7,50E-03	3,02E-07
	CO (kg), to air	2,97E-04	1,40E-04	4,16E-08
	dust (kg), to air	3,68E-06	7,50E-03	2,76E-08

	In/Output	**Waste**	Charac. factors	Characterised
toxicological impacts	Pb (kg), to air	5,66E-09	2,30E+03	1,30E-05
	Pb (kg), to water	1,32E-09	8,60E-01	1,14E-09
	Cd (kg), to air	4,72E-10	1,90E+04	8,96E-06
	Cd (kg), to water	2,64E-11	3,20E+00	8,45E-11
	NO_x (kg), to air	5,64E-05	2,00E-03	1,13E-07
	SO_x (kg), to air	5,58E-05	7,50E-03	4,19E-07
	CO (kg), to air	2,84E-05	1,40E-04	3,98E-09
	dust (kg), to air	1,23E-06	7,50E-03	9,20E-09
	Hg (kg), to air	1,70E-08	4,60E+04	7,81E-04
	Hg (kg), to water	1,13E-10	7,80E+00	8,81E-10
	Cu (kg), to air	5,66E-08	1,45E+02	8,21E-06
	Cr (kg), to air	9,43E-09	3,70E+03	3,49E-05
	Cr (kg), to water	2,26E-10	6,20E-01	1,40E-10

	In/Output	**Fossilgas**	Charac. factors	Characterised
toxicological impacts	NO_x (kg), to air	6,44E-05	2,00E-03	1,29E-07
	SO_x (kg), to air	2,21E-07	7,50E-03	1,66E-09
	CO (kg), to air	1,23E-05	1,40E-04	1,72E-09
	dust (kg), to air	2,12E-08	7,50E-03	1,59E-10

continued, HUMAN HEALTH, Method of characterisation: Jolliet and Crettaz, 1997

	One-step weighting factors (SEK/kg)				
In/Output	10 B	100 B	180 Pb	350 Pb	copper
NO_x (kg), to air					
SO_x (kg), to air					
CO (kg), to air	1,17E-01	1,17E+00	1,10E-05	2,13E-05	
dust (kg), to air	6,25E+00	6,25E+01	5,87E-04	1,14E-03	

	One-step weighting factors (SEK/kg)				
In/Output	10 B	100 B	180 Pb	350 Pb	copper
NO_x (kg), to air					
SO_x (kg), to air					
CO (kg), to air	1,17E-01	1,17E+00	1,10E-05	2,13E-05	
dust (kg), to air	6,25E+00	6,25E+01	5,87E-04	1,14E-03	

	One-step weighting factors (SEK/kg)				
In/Output	10 B	100 B	180 Pb	350 Pb	copper
Pb (kg), to air	1,92E+06	1,92E+07	1,80E+02	3,50E+02	
Pb (kg), to water					7,82E+02
Cd (kg), to air	1,58E+07	1,58E+08	1,49E+03	2,89E+03	
Cd (kg), to water					2,91E+03
NO_x (kg), to air					
SO_x (kg), to air					
CO (kg), to air	1,17E-01	1,17E+00	1,10E-05	2,13E-05	
dust (kg), to air	6,25E+00	6,25E+01	5,87E-04	1,14E-03	
Hg (kg), to air	3,83E+07	3,83E+08	3,60E+03	7,00E+03	
Hg (kg), to water					7,09E+03
Cu (kg), to air	1,21E+05	1,21E+06	1,13E+01	2,21E+01	
Cr (kg), to air	3,08E+06	3,08E+07	2,90E+02	5,63E+02	
Cr (kg), to water					5,64E+02

	One-step weighting factors (SEK/kg)				
In/Output	10 B	100 B	180 Pb	350 Pb	copper
NO_x (kg), to air					
SO_x (kg), to air					
CO (kg), to air	1,17E-01	1,17E+00	1,10E-05	2,13E-05	
dust (kg), to air	6,25E+00	6,25E+01	5,87E-04	1,14E-03	

continued, HUMAN HEALTH, Method of characterisation: Jolliet and Crettaz, 1997

In/Output	One-step weighting factors min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
NO_x (kg), to air	*	*	*	*
SO_x (kg), to air	*	*	*	*
CO (kg), to air	1,10E-05	1,17E+00	3,23E-09	3,43E-04
dust (kg), to air	5,87E-04	6,25E+01	1,44E-09	1,53E-04
			4,1E-08	**4,3E-03**

In/Output	One-step weighting factors min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
NO_x (kg), to air	*	*	*	*
SO_x (kg), to air	*	*	*	*
CO (kg), to air	1,10E-05	1,17E+00	3,27E-09	3,48E-04
dust (kg), to air	5,87E-04	6,25E+01	2,16E-09	2,30E-04
			4,4E-08	**4,7E-03**

In/Output	One-step weighting factors min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
Pb (kg), to air	1,80E+02	1,92E+07	1,02E-06	1,09E-01
Pb (kg), to water	7,82E+02	7,82E+02	1,03E-06	1,03E-06
Cd (kg), to air	1,49E+03	1,58E+08	7,03E-07	7,45E-02
Cd (kg), to water	2,91E+03	2,91E+03	7,68E-08	7,68E-08
NO_x (kg), to air	*	*	*	*
SO_x (kg), to air	*	*	*	*
CO (kg), to air	1,10E-05	1,17E+00	3,12E-10	3,32E-05
dust (kg), to air	5,87E-04	6,25E+01	7,20E-10	7,67E-05
Hg (kg), to air	3,60E+03	3,83E+08	6,11E-05	6,50E+00
Hg (kg), to water	7,09E+03	7,09E+03	8,01E-07	8,01E-07
Cu (kg), to air	1,13E+01	1,21E+06	6,40E-07	6,85E-02
Cr (kg), to air	2,90E+02	3,08E+07	2,74E-06	2,91E-01
Cr (kg), to water	5,64E+02	5,64E+02	1,27E-07	1,27E-07
			6,8E-05	**7,1E+00**

In/Output	One-step weighting factors min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
NO_x (kg), to air	*	*	*	*
SO_x (kg), to air	*	*	*	*
CO (kg), to air	1,10E-05	1,17E+00	1,35E-10	1,44E-05
dust (kg), to air	5,87E-04	6,25E+01	1,24E-11	1,32E-06
			1,0E-08	**1,1E-03**

*) NO_x and SO_x are not accounted for in this category, but valued directly by using the NO_2 and S taxes.

HUMAN HEALTH, Method of characterisation: Environmental Defence Fund (EDF), 1998

	In/Output	**Salix**	Charac. factors	Characterised (kg)	180 Pb	350 Pb	10 B	100 B	malation	diazinon	Value, min (SEK)	Value, max (SEK)
					One-step weighting factors (SEK/kg)							
cancer	NMVOC (kg)	2,14E-05	x									
non-cancer	NO_x (kg)	8,02E-05	x								*	*
	SO_x (kg)	3,97E-05	x								*	*
	CO (kg)	2,93E-04	x									
	dust (kg)	2,45E-06	x									
	NMVOC (kg)	2,14E-05	x									
	NH_3 (kg) to air	2,98E-06	1,50E+00	4,47E-06	4,40E-04	8,60E-04	1,90E+00	1,90E+01	1,20E+02	2,10E-02	**1,3E-09**	**3,6E-04**

	In/Output	**Residues**	Charac. factors	Characterised (kg)	180 Pb	350 Pb	10 B	100 B	malation	diazinon	Value, min (SEK)	Value, max (SEK)
					One-step weighting factors (SEK/kg)							
cancer	NMVOC (kg)	2,29E-05	x									
non-cancer	NO_x (kg)	9,34E-05	x								*	*
	SO_x (kg)	4,03E-05	x								*	*
	CO (kg)	2,97E-04	x									
	dust (kg)	3,68E-06	x									
	NMVOC (kg)	2,29E-05	x									
	NH_3 (kg) to air	2,36E-06	1,50E+00	3,54E-06	4,40E-04	8,60E-04	1,90E+00	1,90E+01	1,20E+02	2,10E-02	**1,0E-09**	**2,8E-04**

	In/Output	**Fossilgas**	Charac. factor
cancer	NMVOC (kg)	2,79E+00	x
non-cancer	NO_x (kg)	6,44E+01	x*
	SO_x (kg)	2,21E-01	x*
	CO (kg)	1,23E+01	x
	dust (kg)	2,12E-02	x
	NMVOC (kg)	2,79E+00	x
	NH_3 (kg) to air	x	

x) data or characterisation factors not available

* NO_x and SO_x are not accounted for in this category, but valued directly by using the NO_2 and S taxes.

HUMAN HEALTH, Method of characterisation: Environmnetal Defence Fund (EDF), 1998

	In/Output	**Waste**	Charac.	Characterised	One-step weighting factors (SEK/kg)								
			factors	(kg)	180 Pb	350 Pb	10 B	100 B	malation	cyan	copper	diazinon	cad
cancer	NMVOC (kg), to air	1,53E-06	x										
	Dioxins (kg) to air	9,43E-12	1,70E+08	1,60E-03	4,40E+09	8,60E+09	3,70E+09	3,70E+10		6,70E+08			
	Pb (kg), to air	5,66E-09	6,80E+00	3,85E-08	1,80E+02	3,50E+02	1,50E+02	1,50E+03		2,70E+01			
	Pb (kg), to water	1,32E-09	5,90E+00	7,79E-09						2,80E+01			
	Cd (kg), to air	4,72E-10	5,00E+01	2,36E-08	1,30E+03	2,60E+03	1,10E+03	1,10E+04		2,00E+02			
	Cd (kg), to water	2,64E-11	7,70E-01	2,03E-11						3,70E+00			
	Cr (kg), to air	9,43E-09	1,90E+01	1,79E-07	4,90E+02	9,60E+02	4,10E+02	4,10E+03		7,40E+01			
	Cr (kg), to water	2,26E-10	x										
non-	NO_x (kg), to air	5,64E-05	x*										
cancer	SO_x (kg), to air	5,58E-05	x*										
	CO (kg), to air	2,84E-05	x										
	dust (kg), to air	1,23E-06	x										
	NMVOC (kg), to air	1,53E-06	x										
	Dioxins (kg), to air	9,43E-12	3,80E+11	3,58E+00	1,20E+08	2,30E+08	4,90E+11	4,90E+12	3,10E+13			5,40E+09	
	Hg (kg), to air	1,70E-08	1,00E+05	1,70E-03	3,00E+01	5,90E+01	1,30E+05	1,30E+06	8,10E+06			1,40E+03	
	Hg (kg), to water	1,13E-10	5,40E+05	6,10E-05					1,80E+06		3,50E+01		1,00E+04
	Pb (kg), to air	5,66E-09	5,90E+05	3,34E-03	1,80E+02	3,50E+02	7,60E+05	7,60E+06	4,80E+07			8,40E+03	
	Pb (kg), to water	1,32E-09	2,50E+05	3,30E-04					8,60E+05		1,60E+01		4,70E+03
	Cd (kg), to air	4,72E-10	1,40E+06	6,60E-04	4,20E+02	8,10E+02	1,80E+06	1,80E+07	1,10E+08			1,90E+04	
	Cd (kg), to water	2,64E-11	1,60E+06	4,22E-05					5,50E+06		1,00E+02		3,00E+04
	Cu (kg), to air	5,66E-08	3,00E+05	1,70E-02	9,30E+01	1,80E+02	3,90E+05	3,90E+06	2,50E+07			4,30E+03	
	Cr (kg), to air	9,43E-09	1,00E+05	9,43E-04	3,20E+01	6,20E+01	1,40E+05	1,40E+06	8,50E+06			1,50E+03	
	Cr (kg), to water	2,26E-10	3,00E+03	6,78E-07					1,00E+04		1,90E-01		5,40E+01
	NH_3 (kg), to air	2,83E-06	1,50E+00	4,25E-06	4,40E-04	8,60E-04	1,90E+00	1,90E+01	1,20E+02			2,10E-02	

*) NO_x and SO_x are not accounted for in this category, but valued directly by using the NO_2 and S taxes.

x) no characterisation factor available

continued, HUMAN HEALTH, Method of characterisation: Environmnetal Defence Fund (EDF), 1998

In/Output	One-step weighting factors min (SEK/kg)	max (SEK/kg)	Value, min (SEK)	Value, max (SEK)
Dioxins (kg) to air	6,70E+08	3,70E+10	6,32E-03	3,49E-01
Pb (kg), to air	2,70E+01	1,50E+03	1,53E-07	8,49E-06
Pb (kg), to water	2,80E+01	2,80E+01	3,70E-08	3,70E-08
Cd (kg), to air	2,00E+02	1,10E+04	9,43E-08	5,19E-06
Cd (kg), to water	3,70E+00	3,70E+00	9,77E-11	9,77E-11
Cr (kg), to air	1,34E-04	4,10E+03	1,26E-12	3,87E-05
Cr (kg), to water				
	*	*	*	*
	*	*	*	*
Dioxins (kg), to air	1,20E+08	3,10E+13	1,13E-03	2,92E+02
Hg (kg), to air	3,00E+01	8,10E+06	5,09E-07	1,38E-01
Hg (kg), to water	3,50E+01	1,80E+06	3,96E-09	2,03E-04
Pb (kg), to air	1,80E+02	4,80E+07	1,02E-06	2,72E-01
Pb (kg), to water	1,60E+01	8,60E+05	2,11E-08	1,14E-03
Cd (kg), to air	4,20E+02	1,10E+08	1,98E-07	5,19E-02
Cd (kg), to water	1,00E+02	5,50E+06	2,64E-09	1,45E-04
Cu (kg), to air	9,30E+01	2,50E+07	5,26E-06	1,42E+00
Cr (kg), to air	3,20E+01	8,50E+06	3,02E-07	8,02E-02
Cr (kg), to water	1,90E-01	1,00E+04	4,29E-11	2,26E-06
NH_3 (kg), to air	4,40E-04	1,20E+02	1,25E-09	3,40E-04
			7,5E-03	**2,9E+02**

APPENDIX 3

Calculations of MI-factors for energy input figures.

Coal:
Calorific value = 27 500 MJ/ton
MI-abiotic (including electricity) = 2.11 ton/ton

2.11 [ton/ton] / 27 500 [MJ/ton] * 3.6 [MJ/kWh] = $2.8*10^{-4}$ ton/kWh

Fossilgas *(Wuppertal Institute, 1999)*
Calorific value = 41 000 MJ/ton
MI-abiotic (including electricity) = 1.22 ton/ton

1.22 [ton/ton] / 41 000 [MJ/ton] * 3.6 [MJ/kWh] = $1.1*10^{-4}$ ton/kWh

Oil *(Wuppertal Institute, 1999)*
Calorific value = 42 800 MJ/ton
MI-abiotic (including electricity) = 1.36 ton/ton

1.36 [ton/ton] / 42 800 [MJ/ton] * 3.6 [MJ/kWh] = $1.1*10^{-4}$ ton/kWh

Biofuel *(Energifakta, 1994)*
The figures for biofuel only express the own weight, the ecological rucksack is not accounted for.

The energy content of forest cultivated for energy is 7.9 GJ_{fuel}/ton (50% moisture) and 12.1 GJ_{fuel}/ton (30% moisture) *(Energifakta, 1994)*. The assumption made in the report of 80% on site splintered (50% moisture) and 20% stored (30% moisture) for Salix is used here as an approximation of moisture level *(IVL, 1999).*

(0.8 * 7.9 + 0.2 * 12.1) $*10^3$ [MJ/ton] = $8.74*10^3$ MJ/ton

3.6 [MJ/kWh] / $8.74*10^3$ [MJ/ton] = $0.41*10^{-3}$ ton/kWh