Life Cycle Assessments of Energy from Solid Waste

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Preface

This is a report from the two-year project "Future Oriented Life Cycle Assessments of Energy from Solid Waste". The project is financially supported by the Swedish National Energy Administration and is a part of the research programme "Energy from Solid Waste".

In our work we have benefited from support from a number of persons and organisations. We would specifically like to acknowledge some of them, while recognising the risk of having forgotten some. The co-operation with the ORWARE team has been useful, stimulating and important for us. Special thanks to Jan-Olov Sundqvist (IVL), Andras Baky (JTI), Anna Björklund (KTH), Marcus Carlsson (IVL and SLU), Magnus Dalemo (JTI), Ola Eriksson (KTH), Björn Frostell (KTH), Jessica Granath (IVL). Discussions with members of other project teams (especially Johan Sundberg et al at Chalmers) and Bengt Blad, Anna Lundborg and others at Energimyndigheten at workshops and other occasions have also been valuable. Also thanks to Martin Erlandsson (IVL), Hans-Olof Marcus (IVL), Stefan Uppenberg (IVL) for different kinds of help with data. Thanks also to Lars Olsson at Assi Domän Kraftliner in Piteå for helping out with data and information regarding corrugated cardboard and to Johan Ericson at Uppsala Energi AB for information about the incineration plant in Uppsala. We are grateful to Anna Björklund (KTH), Björn Eriksson (fms) and Daniel Jonsson (fms) for giving us comments on a draft of this report.

GF wants to thank co-authors of papers written within this project (se below); especially Prof. Roland Clift (University of Surrey, Guildford, U.K.), Dr. Tomas Ekvall (Chalmers Industriteknik, Gothenburg) and Dr. Per Nielsen (Technical University of Denmark, Lyngby, Denmark). Also thanks to members of the International Expert Group on Integrated Solid Waste Management and Life Cycle Assessment initiated by Terry Coleman (Environment Agency of England and Wales) and Susan Thorneloe (USEPA), for inspiring discussions.

Finally we would like to acknowledge the late Prof Peter Steen. He created fms (Environmental Strategies Research Group), an inspiring place for research on the interaction between environmental issues and society's development and contributed in many ways to this project. We miss him a lot.

This report has a number of appendices. Appendix 1 is attached to this report. The other appendices are published as separate reports that are available on our homepage: www.fms.ecology.su.se or directly from fms. The following appendices are available:

1. Sources for data on additives, energy and transports. Included in this report.
2. Classification and characterisation and weighting factors. Report fms 138.
3. Undefined substances in the base scenario. Report fms 139.
4. Weighted results for all waste fractions and all scenarios. Report fms 140.
5. Process data records in Sima Pro 4.0. Report fms 141.
6. Inventory results for all scenarios. Report fms 142.
7. Characterisation results for the base scenario. Report fms 143.

Besides this report, there are a number of other publications which have been produced wholly or partially within this project (se below), and more publications can be expected.

Clift, R., Doig, A. and Finnveden, G. (2000): The Application of Life Cycle Assessment to Integrated Solid Waste Management, Part I – Methodology. *Transactions of the Institution of Chemical Engineers, Part B: Process Safety and Environmental Protection*. In press.

Ekvall, T. and Finnveden, G. (2000): The Application of Life Cycle Assessment to Integrated Solid Waste Management, Part II – Perspectives on energy and material recovery from paper. . *Transactions of the Institution of Chemical Engineers, Part B: Process Safety and Environmental Protection*. In press.

Ekvall, T. and Finnveden, G. (2000): Allocation in ISO 14041 – A Critical Review. *J. Cleaner Prod.* In press.

Finnveden, G. (1998): Life Cycle Assessment of Integrated Solid Waste Management Systems. In Sundberg, J., Nybrandt, T. and Sivertun, Å. (Eds): System engineering models for waste management, AFR-Report 229, 261-275, AFN, Swedish EPA, Stockholm, Sweden.

Finnveden, G. (1998): Snävt perspektiv i norska rapporten, Energibesparing kan göras. RVF-nytt, Nr 4 1998, 10-11.

Finnveden, G. (1999): Livscykelanalyser – ett verktyg för miljöutvärdering av energisystem, alternativa energikällor och nya energitekniker. Referat av föredrag vid Sveriges Energiting –99. Energimyndigheten, Eskilstuna.

Finnveden, G. (1999): Methodological Aspects of Life Cycle Assessment of Integrated Solid Waste Management Systems. *Resources, Conservation and Recycling*, 26, 173-187.

Finnveden, G. (2000): Challenges in LCA Modelling of Landfills. Submitted.

Finnveden, G. (2000): Många rapporter säger tvärtom. Dagens Nyheter, 29 februari, sid A22.

Finnveden, G. and Ekvall, T. (1999): Environmental aspects of energy and material recovery of paper – today and in a more sustainable future. Appendix VII in Ekvall, T.: System Expansion and Allocation in Life Cycle Assessment, With Implications for Waste Paper Management. Dissertation, Chalmers University of Technology.

Finnveden, G. and Nielsen, P.H. (1999):Long-term emissions from landfills should not be disregarded! Letter to the Editor. *Int. J. LCA*, 4, 125-126.

Finnveden, G., Johansson, J., Lind, P. och Moberg, Å. (2000): Återvinning mest energieffektivt. Inskickat till RVF-nytt.

Finnveden, G., Johansson, J., Lind, P. and Moberg, Å. (2000): Treatment of solid waste – What makes a difference? Abstract presented at the third SETAC World Congress, Brighton, United Kingdom, 21-25 May.

Finnveden, G., Johansson, J., Lind, P. and Moberg, Å. (2000): Environmental effects of landfilling of solid waste compared to other options – assumptions and boundaries in life cycle assessment. Abstract accepted for presentation at the Intercontinental Landfill Research Symposium, Luleå, December 11-13.

Lind, P. (1999): *En livscykelinventeringsmodell för hantering av fast hushållsavfall på nationell nivå.* Examensarbete. Nr 72, Ekotoxikologiska avdelningen, Uppsala universitet.

Lind, P. (1999): Appendix till examensarbete. fms rapport 111.

Moberg, Å. (1999):*Environmental Systems Analysis Tools – differences and similarities, including a brief case study on heat production using Ecological footprint, MIPS, LCA and exergy analysis*, Stockholms universitet, Inst för Systemekologi, Examensarbete 1999:8.

Abstract

The overall aim of the present study is to evaluate different strategies for treatment of solid waste based on a life-cycle perspective. Important goals are to identify advantages and disadvantages of different methods for treatment of solid waste, and to identify critical factors in the systems, including the background systems, which may significantly influence the results. Included in the study are landfilling, incineration, recycling, digestion and composting. The waste fractions considered are the combustible and recyclable or compostable fractions of municipal solid waste. The methodology used is Life Cycle Assessment. The results can be used for policy decisions as well as strategic decisions on waste management systems.

Summary

We live in a changing world. In many countries both energy systems and waste management systems are under change. The changes are largely driven by environmental considerations and one driving force is the threat of global climate change. When making new strategic decisions related to energy and waste management systems it is therefore of importance to consider the environmental implications.

A waste hierarchy is often suggested and used in waste policy making. Different versions of the hierarchy exist but in most cases it suggests the following order:

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

The first priority, to reduce the amount of waste, is in general accepted. However, the remaining waste needs to be taken care of as efficiently as possible. Different options for taking care of the remaining waste is the topic of this study. The hierarchy after the top priority is often contested and discussions on waste policy are in many countries intense. Especially the order between recycling and incineration is often discussed. Another question is where to place biological treatments such as anaerobic digestion and composting in the hierarchy. One of the aims of this study is to evaluate the waste hierarchy.

The overall aim of the present study is to evaluate different strategies for treatment of solid waste based on a life-cycle perspective. Important goals are to identify advantages and disadvantages of different methods for treatment of solid waste, and to identify critical factors in the systems, including the background systems, which may significantly influence the results. Included in the study are landfilling, incineration, recycling, digestion and composting. The waste fractions considered are the combustible and recyclable or compostable fractions of municipal solid waste.

The methodology used is Life Cycle Assessment. An LCA studies the environmental aspects of a product or a service (in this case waste management) from “cradle to grave (i.e. from raw material acquisition through production, use and disposal). The methodology used is as far as possible based on established methods and practices for both the inventory analysis and the characterisation element of the life cycle impact assessment. In the weighting step, two methods are used, Ecotax 98 and Eco-indicator 99. The focus is on overall energy use and emissions of gases contributing to global warming, but other impact categories such as acidification, eutrophication, photo-oxidant formation, human and ecotoxicological impacts are also included. In the study a base scenario is defined. In several alternative scenarios different assumptions are tested by changing them.

All waste treatment processes considered in this study produce some useful products: materials, fertilisers, fuels, heat or electricity, which can replace the same product produced in another way. This is taken into account in the studied systems. The environmental aspects of different waste treatment methods are therefore not only determined by the properties of the treatment method itself, but also by the environmental properties of the product that can be replaced and the environmental impacts associated with its life cycle.

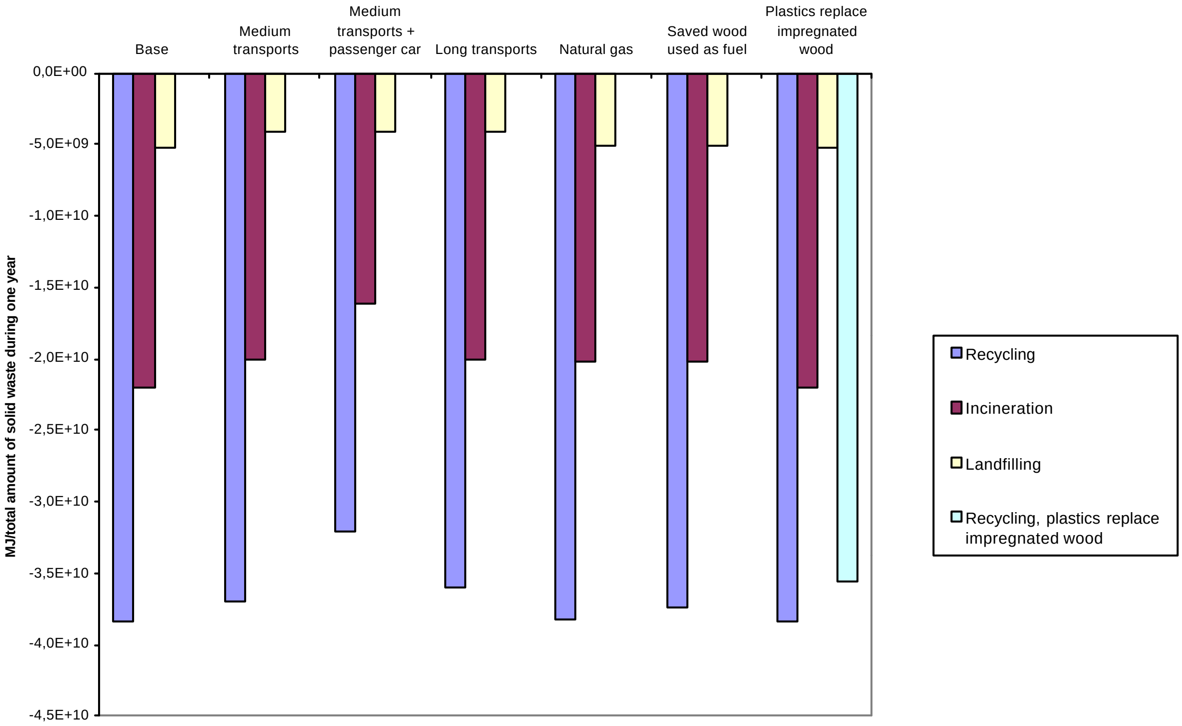

Figure 1. The total energy use for the whole system in a number of scenarios

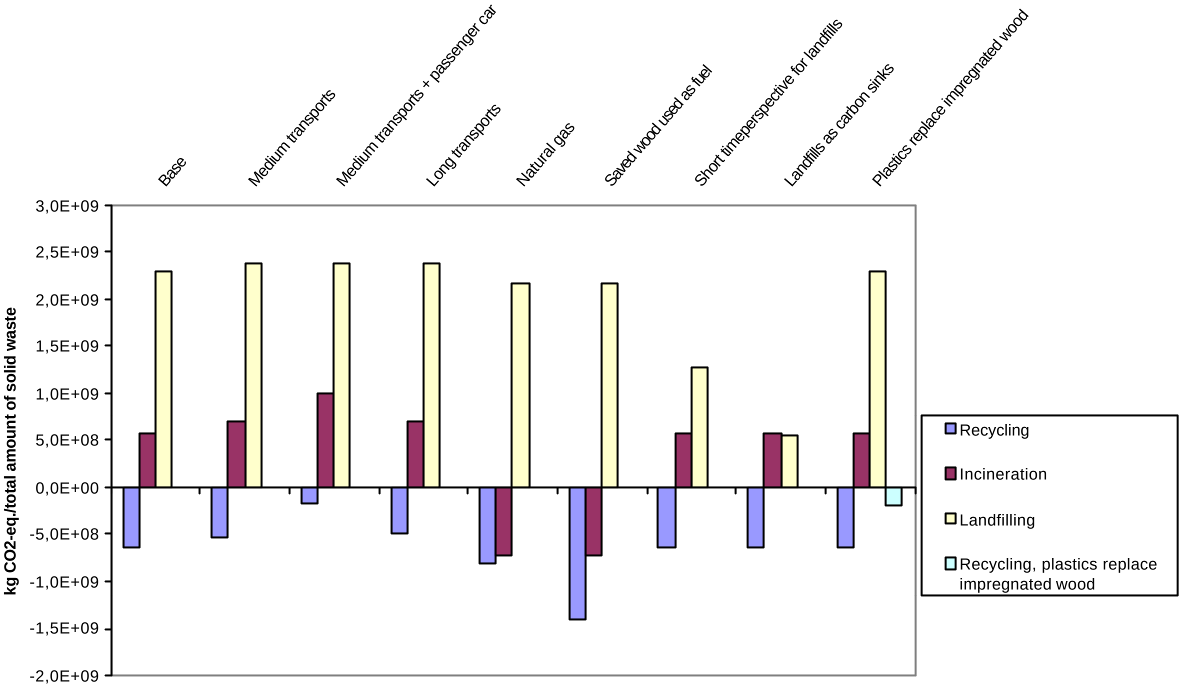

Figure 2. Contribution to global warming from the whole system in different scenarios.

To summarise some of the overall conclusions it can be noted that recycling of paper and plastic materials are in general favourable according to our study with regard to overall energy use, emissions of greenhouse gases and the total weighted results. These results are fairly robust. When looking at total energy use and emissions of greenhouse gases, recycling is the preferred strategy in all scenarios for the whole system, i.e. when all the studied waste fractions are included. In Figures. 1 and 2 the results from several scenarios are shown compared to the base scenario. In the scenario “medium transports” the transport distances are increased compared to the base scenario and passenger cars are also assumed to be used in one scenario. In the scenario “long transports”, transportation distances are further increased compared to the “medium transports” scenario. In the scenario “natural gas”, it is assumed that the heat from incineration of waste and gas from digestion and landfilling replaces heat from incineration of natural gas. This is a change from the base scenario where it is assumed that the competing heat source is forest residues. In the scenario “saved wood used as fuel” it is assumed that the wood that is “saved” by recycling of paper materials is used as a fuel for heat production replacing natural gas. Such a scenario can correspond to a situation where there is increased competition for biomass. In the base scenario, emissions from landfills are considered for a hypothetical infinite time period. In the scenario “Short time perspective for landfills” this is changed. Also in the scenario “landfills as carbon sinks” only a short time perspective is considered and landfills are modelled as carbon traps for nondegraded biological materials. In the scenario, “Plastics replace impregnated wood” it is assumed that recycled plastics replace impregnated wood as palisades. This is a change from the base scenario where it is assumed that recycled paper and plastic materials replace the same materials produced from virgin raw materials.

One exception to the general results is plastics when they are recycled and replace impregnated wood. In this case recycling of plastics is less favourable than incineration with respect to energy use and emissions of greenhouse gases although the difference is rather small. However, recycling may still be favourable with respect to toxicological impacts, and our results still show a benefit for recycling with regard to the total weighted results.

Incineration is in general favourable over landfilling according to our study with regard to overall energy use, emissions of gases contributing to global warming and the total weighted results. There are however some aspects which may influence this ranking. If longer transportation distances are demanded in the incineration case, especially by passenger cars, landfilling can become more favourable than incineration. The modelling of landfills can also have a decisive influence. If shorter time periods are used, in the order of a century, landfilling is favoured and may become a preferable option over incineration.

LCAs can be used to test the waste hierarchy and identify situations where the hierarchy is not valid. Our results suggest however that the waste hierarchy is valid as a rule of thumb. The results presented here can be used as a basis for policy decisions as well as strategic decisions on waste management systems.

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ABBREVIATIONS

Abbreviations

AOX	Adsorbable halogenated organic material
BOD	Biological oxygen demand
CFB	Circulating fluidised bed
CHX	Volatile halogenated hydrocarbons
COD	Chemical oxygen demand
DALY	Disability adjusted life years
DEHP	Dietyl-hexyl-ftalat
DOC	Dissolved organic compounds
DOM	Dioktyl-tin-maliat
EDIP	Environmental design of industrial products
EIA	Environmental Impact Assessment
GWP	Global warming potential
HBFC	Bromine-containing halocarbons
HDO	Bis-(N-cyclohexyldiazenium-dioxy)
HDPE	High density polyethylene
HHV	Higher heating value
LCA	Life Cycle Assessment
LCIA	Life Cycle Impact Assessment
LHV	Lower heating value
LPG	Liquefied petroleum gas
NMVOC	Non-methane volatile organic compounds
NT waste	Non-treated waste
ODP	Ozone depletion potential
PAF	Potentially affected fraction
PAH	Polyaromatic hydrocarbons
PCB	Polychlorinated biphenyls
PET	Polytethyleneterephtalate
POCP	Photochemical ozone creation potential
PP	Polypropylene
PS	Polystyrene
PVC	Poly(vinyl chloride)
RA	Risk Analysis
Ra	Required acreage
RT	Remaining time period
SFA	Substance Flow Analysis
SNCR	Selective non-catalytic reduction
SP	Sima Pro 4.0
SPOLD	Society for Promotion of Life Cycle Assessment Development
ST	Surveyable time period
TMP	Thermo mechanical pulp
TMT 15	Trimercapto-s-triazine-tri-sodium-salt
TOC	Total organic carbon
TS	Total solids

USES	Uniform system for the evaluation of substances
VOC	Volatile organic compounds
YLD	Numbers of years lived disabled
YLL	Numbers of years of life lost

1 Introduction

1.1 Background

We live in a changing world. In many countries both energy systems and waste management systems are currently undergoing changes. One driving force for these changes is the threat of global climate change caused by increasing concentrations of carbon dioxide (CO_2), methane (CH_4) and other greenhouse gases. This threat has lead the global society to sign the Kyoto protocol 1997 which simplistically states that the developed countries should reduce their emissions by 5 % until the year 2010 compared to 1990 (SOU 2000). These reductions will however probably be followed by more stringent reductions. For example, a recent parliamentary committee in Sweden (SOU 2000) has suggested that the Swedish emissions of greenhouse gases should be reduced by 2 % until the year 2010 and by 50 % until the year 2050 with further reductions after that (SOU 2000). In Sweden the energy system is being changed, not only because of the threat of global climate change but also because of the planned phase out of nuclear power, deregulation of the electricity markets and following increased possibilities for import and export of power between different markets among other things.

One way of reducing emissions of greenhouse gases from the energy system is to reduce the use of fossil fuels. In many countries there is currently ongoing discussions on how to reduce the use of fossil fuels and increase the use of renewable fuels. Waste is sometimes regarded as a renewable fuel. Policies on waste management systems should therefore be considered together with policies on energy systems. Another way of reducing emissions of greenhouse gases is to reduce emissions of methane (CH_4) from degradation of organic materials in landfills. This is one reason for the policy in many countries to reduce landfilling of organic materials.

The waste management systems in Sweden are affected by the recent decision on a landfill tax and the decision to stop landfilling of organic waste after the year 2005. Investments must therefore be made in alternative management options for the waste that is currently being landfilled. Before making such investments it is important to examine the consequences of different choices. This study is intended as one basis for strategic decisions regarding waste management energy policies.

A waste hierarchy is often suggested and used in waste policy making. Different versions of the hierarchy exist but in most cases it suggests the following order:

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

The first priority, to reduce the amount of waste, is in general accepted. However, the remaining waste needs to be taken care of as efficiently as possible. Different options for taking care of the remaining waste is the topic of this study.

The hierarchy after the top priority is often contested and discussions on waste policy are in many countries intense. Especially the order between recycling and incineration is often discussed. Another question is where to place biological treatments such as anaerobic digestion and composting in the hierarchy. One of the aims of this study is to evaluate the waste hierarchy.

1.2 Life Cycle Assessment

It is interesting to note that the changes in both energy and waste management systems to a large extent are driven by environmental considerations and arguments. It is therefore of importance when making decisions on policies as well as on investments to consider the environmental implications. A large number of methods and tools for describing environmental aspects have been developed which can be used in different types of decision contexts (Moberg et al. 1999). In this study we are using Life Cycle Assessment for comparing different alternative waste treatment strategies.

Life Cycle Assessment (LCA) studies the environmental aspects and potential impacts throughout a product's life (i.e. from cradle to grave) from raw material acquisition through production, use and disposal (ISO 1997). The LCA methodology is described in detail in chapter 2. Here it is of interest to note two important aspects of LCA, which makes the tool unique. The first is the focus on products, or rather functions that products provide. Products can include not only material products but also service functions, for example taking care of a certain amount of solid waste or producing a certain amount of heat or electricity. This is an appropriate perspective when comparing different options for waste treatment or methods for generating heat and electricity.

The second aspect of LCA is the cradle-to-grave perspective. When comparing different products fulfilling a similar function it can be important to consider the complete life cycle. This is because environmental impacts and benefits may occur at different phases of the life-cycle. Here are two examples of relevance for both energy and waste management policies, which illustrate the need to consider wide enough system boundaries in a reasonably standardised procedure (Finnveden 1999a):

- Ethanol can be produced from paper fractions of solid waste. The ethanol can be used as a fuel for buses with, in general, less emissions of pollutants than for example diesel fuels during the use phase. However, the production of ethanol is energy demanding and if fossil fuels are used for the production, the total result of the complete life cycle is not in favour of the ethanol alternative (Finnveden et al. 1994).

- Recycling, incineration and landfilling of waste material were compared in a recent cost-benefit analysis by Bruvoll (Bruvoll 1998). However, the system boundaries of the study were too narrow for a fair comparison. For example, increased transports of recycled materials were included but not decreased transports of virgin material which was assumed to be replaced by the recycled material (Finnveden 1998).

LCA is currently being used in several countries to evaluate different strategies for Integrated Waste Management, e.g. Finnveden and Huppes (1995), White et al. (1995), Denison (1996), Aumônier and Coleman (1997), Sundberg et al. (1998), Hassan et al. (1999), Tukker (1999a, b), Weitz et al. (1999), Clift et al. (2000), Sundqvist et al. (2000) and to evaluate treatment options for specific waste fractions, e.g. paper Finnveden and Ekvall (1998), Ekvall and Finnveden (2000c) and plastics Heyde and Kremer (1999).

1.3 Aim and scope of present study

The overall aim of the present study is to evaluate different strategies for treatment of solid waste based on a life-cycle perspective. Important goals are to identify advantages and disadvantages of different methods for treatment of solid waste, and to identify critical factors in the systems, including the background systems, which may significantly influence the results. The results are intended to be used by decision-makers in local, regional and national authorities and industries as one basis for decisions on strategies and policies for waste management and investments for new waste treatment facilities. Some aspects of the scope are:

- The focus is on Swedish conditions, but it is expected that much of the results will be of interest also for other countries
- The intended use is for assessing effects of different strategic choices made today or the coming years. These effects will however prevail for decades since the lifetime of the investments will be comparatively long. The time frame of the treatment systems is therefore extended from the current situation to several decades into the future.
- Included in the study are fractions of municipal solid waste, which are combustible and recyclable or compostable.
- The focus is on energy use and climate change although other impact categories such as acidification, eutrophication, photo-oxidant formation and human and ecotoxicological impacts are also considered.

The scope of the study is further defined in section 2.3.

1.4 Some guidance to the reader

In chapter 2, LCA methodology is presented and discussed. Section 2.1 is a general presentation of LCA methodology and can be skipped by those familiar to LCA. Section 2.2 contains a discussion on some methodological issues of special relevance for LCA of waste management systems. Section 2.3 includes a presentation of methodological choices made in this study and it is probably of importance for any reader who wants to have something more than just a quick feeling of the report. The methodological choices made for the impact assessment are partly described in section 2.3 and in more detail in chapter 6. Section 2.4 contains a description of the LCA software programme that is used.

Chapter 3 contains a description of the scenarios used in this study (one base scenario and several “what-if scenarios”) and some major assumptions. At the end of the chapter there is a summary which may be enough to read for some readers of this report.

Chapter 4 contains detailed descriptions of the waste materials studied and the amounts of them. Chapter 5 contains detailed descriptions of the processes included in the study. Many readers are probably not interested in all the details of these chapters.

Chapter 7 contains a fairly detailed presentation of the results of all scenarios. Many readers may not be interested in all the details of this chapter and may look at some of the tables and go directly to chapter 8, using chapter 7 as a reference for aspects of particular interest.

Appendix 1 includes data on additives, energy and transports used in this study, which are mentioned in chapter 5 but not described in detail there. Appendix 1 is included in this report. Appendix 2-7 are available as separate reports, see preface for details on contents.

2 Methodology

2.1 General LCA methodology

2.1.1 Introduction

This section is devoted to a brief introduction to life cycle assessment. The presentation is based on UNEP (1996) in addition to a number of LCA references such as Lindfors et al. (1995), Udo de Haes (1996), Frischknecht (1997), ISO (1997), Weidema (1998), ISO (1999), Johansson (1999), Udo de Haes et al. (1999a), Udo de Haes et al. (1999b), Clift et al. (2000) and Finnveden (000a)

In a life cycle assessment (LCA) the environmental impacts of a product or service are investigated throughout its whole life cycle. This is done by compiling an inventory of relevant inputs and outputs of a system (inventory analysis), evaluating the potential impacts of those inputs and outputs (impact assessment), and interpreting the results (interpretation) in relation to the objectives of the study (defined in the scope and goal definition in the beginning of the study) (ISO 1997). A standardised framework on how to perform an LCA is provided by the International Standards Organisation (ISO 1997). According to this framework a life cycle assessment consists of four different, but interrelated phases, as illustrated in Figure 2.1. The different phases of LCA are described below, mainly based on the ISO-standard.

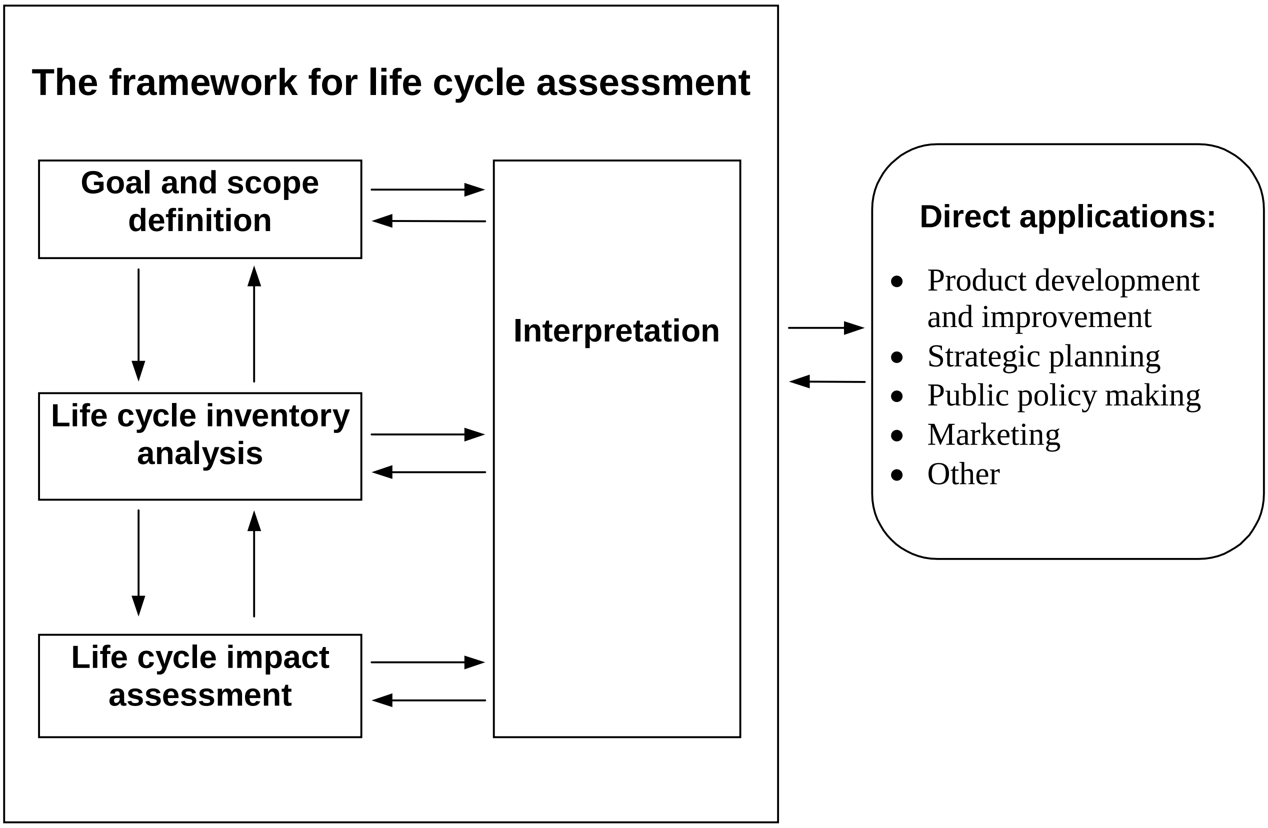

Figure 2.1. The phases of a life cycle assessment (modified from ISO (1997).

The LCA shall cover the use of material and energy as well as all emissions made by the product system in a cradle-to-grave perspective. As defined in the Nordic Guidelines on Life Cycle Assessment (Lindfors et al. 1995), this means that the product system is followed from the extraction and processing of raw material, through manufacturing, distribution, use, reuse, maintenance, recycling to final disposal, including all transports involved. Quantitative or qualitative information on emissions made, and material and energy used in all those phases are gathered and processed so that an assessment can be made on the total impact on the environment and on the resource base. An LCA does not involve economic or social impacts (Lindfors et al. 1995). The general categories of environmental impacts needing attention include resource use, human health and ecological considerations (ISO 1997).

An LCA study can be a valuable support for various kinds of environmental decisions, such as the design or improvement of products and processes, the development of business plans, the setting of ecolabeling criteria, the developing of policy strategies, and when making purchasing decisions.

The focus of an LCA may be either on a product, such as a car, or on a function, such as the transportation of one person from point A to point B. The LCA is always based on a so called functional unit. The functional unit is a reference unit for quantifying the performance of a product system. When for example comparing washing up by hand with using a dishwasher, the functional unit could be the washing-up needed by a four-person household for one year. This approach gives a *relative* indication of what potential damage the product system might give rise to, and an LCA can thus never tell what actual damage that is going to occur in the environment.

There are several other environmental decision tools available addressing different aspects, for example risk analysis (RA) for hazardous chemicals and activities; environmental impact assessment (EIA) for new activities; and substance flow analysis (SFA) for substances. The different techniques should not be seen as competitive, but rather as complementary. (For a comparison of different environmental analysis tools, se e.g. Moberg et al. (1999).

Performing an LCA is an iterative process, where information revealed during the course of the study may impose a revision of earlier steps. As, for example, the most important processes are identified, the scope of the study may have to be altered. The process is repeated until the goal of the study is met.

2.1.2 Goal and scope definition

In the goal of an LCA study the intended application and the reasons for carrying out the study shall be clearly stated. It shall also be defined to whom the results produced are intended to be communicated.

The goal set in turn defines the scope needed for the study in order to meet that goal. In the scope the functions of the system under study are specified, and the functional unit, on which the investigation shall be based, is determined.

It is unfeasible to cover absolutely every aspect linked to the life of a product. Therefore the system boundaries have to be determined. That is, a decision concerning which unit processes to be included within the LCA has to be made. The data quality required to fulfil the goal of the study is also specified in the scope, addressing issues like time related coverage, geographical coverage, and consistency and reproducibility of the methods used. In comparative studies any differences between systems, regarding functional unit and methodological considerations shall be identified and reported.

The goals of an LCA can be analysed in several dimensions. A first fundamental dimension is concerned with whether the study is change-oriented (prospective) or descriptive (retrospective) (Frischknecht 1997, Baumann 1998, Weidema 1998). If the study is change-oriented it analyses the consequences of a choice; ideally the data used should reflect the actual changes taking place, and may depend on the scale of the change and the time over which it occurs. With regard to time, a distinction can be made between a very short time frame (less than a year), short (years), long (decades) or very long (centuries). Studies which are not change-oriented may be called environmental reports. In such studies the appropriate data should reflect what was actually happening in the system (Clift et al. 2000).

For a change-oriented, prospective study, the ideal data is in general some sort of marginal data reflecting the actual change (Tillman 1999, Weidema et al. 1999a). A procedure for identification of the marginal has been suggested by (Weidema et al. 1999a). If the time perspective is long (decades) it is in general changes in the base-load marginal that are of relevance. The long-term base-load marginal is determined by several aspects, e.g. if the total market is increasing or decreasing and if there are any aspects constraining the use of a specific technology. If the total market is increasing, new investments will be made. The base-load marginal technology is the technology in which new investments are made. This is the preferred, unconstrained technology (Weidema et al. 1999a). If the market is decreasing, production capacity will be decreased and the marginal technology is the technology that will be decreased. This is the least preferred technology (Weidema et al. 1999a).

2.1.3 Life cycle inventory analysis

The inventory analysis is the phase when data is collected and calculations are made in order to specify relevant inputs to and outputs from the product system. This work can be divided into four different substeps (UNEP 1996) which in practise are performed simultaneously.

First, all processes involved in the life cycle of the product system have to be identified. Ultimately, all processes start with the extraction of raw materials and energy from the environment. After the transformation by various economic processes, all those inputs from the environment will eventually re-enter the environment as emissions to air, water and land. To clarify these often complex processes, a process flow chart is constructed.

Secondly, the data on each process is collected. This is the most time consuming and difficult task in performing an LCA. Data can be obtained from scientific literature, from published data files used by LCA practitioners, from industry and from government records. The data used should preferably be quantitative, but when it proves too difficult to find quantitative data a qualitative estimation can be made instead.

The third step is to define once again the system boundaries. This time it can be done more carefully with the information from the system flow chart and the collected data. This will give the LCA study a more manageable size, as processes that fall outside these boundaries can be left out. Boundaries need to be set separating the product system from the environment, from other product systems and from processes not taken into account in the product system (UNEP 1996). The system boundary between the studied product system and other product system boundaries leads to so called allocation problems, which are further discussed below.

Finally, the inputs and outputs from all processes are adjusted to relate to the functional unit. Aggregation of all data, through addition, then results in an inventory table. In the inventory table all economic inputs and outputs will have been translated into environmental inputs and outputs, in terms of resource extraction and emissions.

2.1.4 Life cycle impact assessment

As the inventory table often contains a vast number of figures, that are difficult to interpret intuitively, the need for a more formalised evaluation arises. The inventory table constitutes the input to the life cycle impact assessment (LCIA). According to the ISO-standard (ISO 1999), the LCIA is a phase of the LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. It is divided into several elements; some are described as mandatory in an LCIA and some as optional.

The first mandatory element is a selection of a manageable number of impact categories of resource use and environmental impacts, indicators for the categories and models to quantify the contributions of different inputs and emissions to the impact categories. As an example of impact categories that may be discussed in an LCIA, Table 2.1 presents a default list suggested by the SETAC-Europe working group on LCIA (Udo de Haes 1996). In practice however, a shorter list of impacts are normally included in current LCAs (Finnveden 2000a). The second mandatory element **(classification)** is an assignment of the inventory data to the impact categories. The third mandatory element **(characterisation)** is a quantification of the contributions to the chosen impacts from the product system.

Table 2.1. Default list of impact categories for life cycle impact assessment (Udo de Haes 1996).

Input related categories
1. Abiotic resources (deposits, funds, flows)*
2. Biotic resources (funds)
3. Land

Output related categories
4. Global warming
5. Depletion of stratospheric ozone
6. Human toxicological impacts
7. Ecotoxicological impacts
8. Photo-oxidant formation
9. Acidification
10. Eutrophication (incl. BOD and heat)
11. Odour
12. Noise
13. Radiation
14. Casualties

Pro memoria: Flows not followed to the system boundary
Input related
Output related

*Deposits are resources which can only be depleted, with no renewability within the timeframe considered (examples include mineral ores and fossil fuels). Funds are resources which are intrinsically renewable but which can be depleted (examples include wood and fish). Flows are resources which can be deflected and used but not depleted (examples include wind and solar radiation).

There are also several optional elements which can be used depending on the goal and scope of the LCA (ISO 1999). **Normalisation** relates the magnitude of the impacts in the different categories to reference values; an example of a reference value is the total contribution to an impact category by a nation. **Grouping** includes sorting and possibly ranking of the indicators. **Weighting** aims at converting and possibly aggregating results across impact categories resulting in a single result, sometimes with a monetary measure. The final element is a data quality analysis, which is described as mandatory in comparative assertions.

Weighting is and has always been a controversial issue, in large part because this element requires social, political and ethical values e.g. Finnveden (1997) whereas the preceding steps are based on more traditional natural sciences. Another aspect is that most of the presently available weighting methods for LCA seem to have significant drawbacks (Finnveden 1999b). The controversy around Weighting as an element in the analysis and weighting methods is also illustrated by the ISO standard, which states that weighting shall not be used in “comparative assertions disclosed to the public”(ISO 1999).

It is sometimes noted, e.g. in the ISO standard (ISO 1999), that the methodological and scientific framework for LCIA is still being developed. Methods for different impact categories are in different stages of development. Work is currently ongoing to develop a set of best available practices regarding impact categories and category indicators (Udo de Haes et al. 1999a, Udo de Haes et al. 1999b).

The relations between the Inventory Table, Classification and Characterisation and Weighting are illustrated in Figure 2.2.

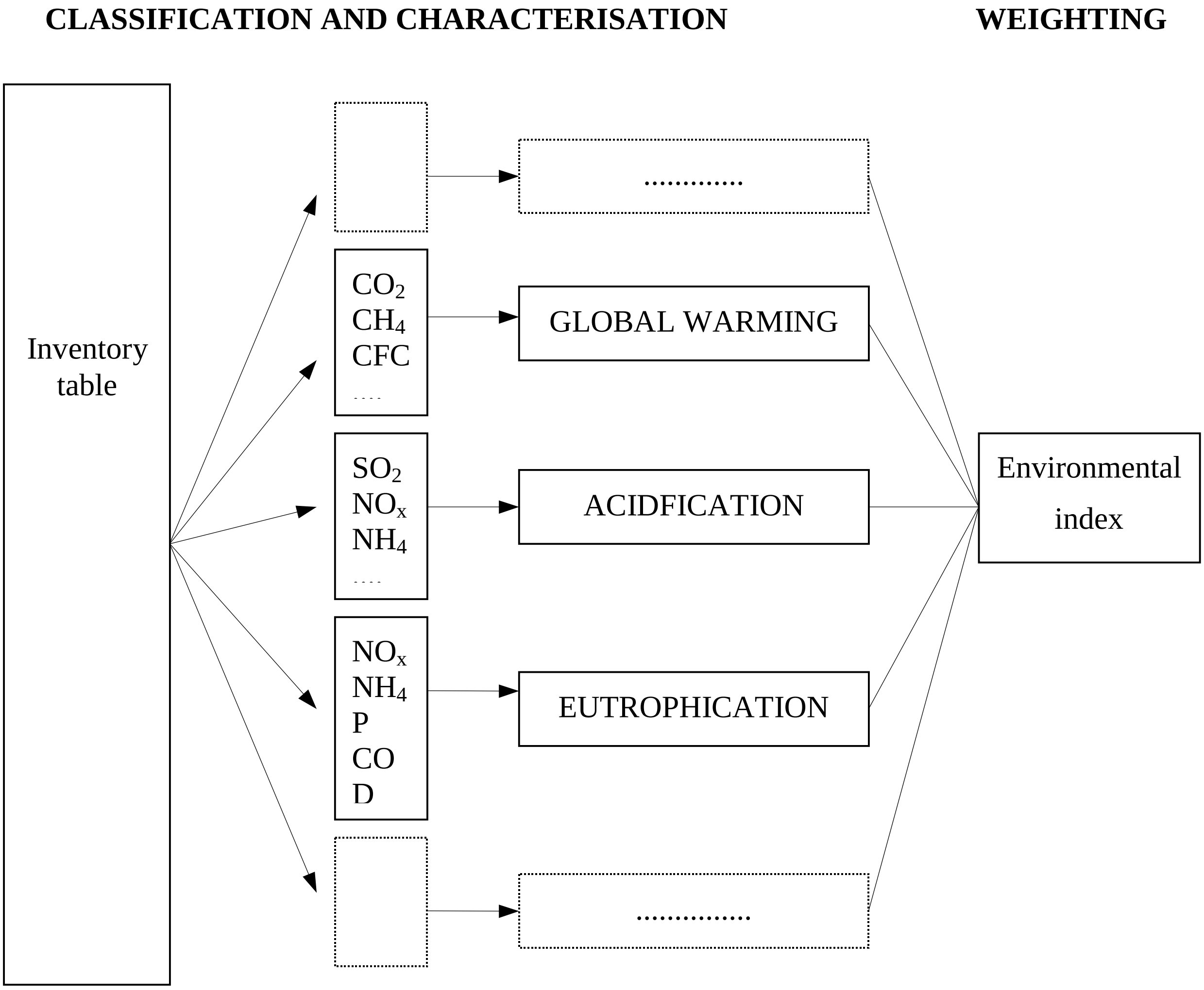

Figure 2.2. Some of the steps involved in the life cycle impact assessment (modified from UNEP (1996).

2.1.5 Interpretation

In the interpretation phase of LCA the findings from the inventory analysis and the impact assessment are combined together in order to reach conclusions and recommendations, consistent with the goal and scope of the study (ISO 1997). This phase may also involve the reviewing and revising of the goal and scope, as well as the nature and quality of the data collected.

2.2 LCA Methodology and Integrated Solid Waste Management

The general LCA methodology has been described above. Essentially the same methodology can be applied when applied to waste management systems although different aspects of the methodology may come into focus. It is also important to notice that although improvements have been made to LCA methodology, there are still a number of unresolved issues, which need further attention (Udo de Haes and Wrisberg 1997). Here, some methodological aspects of relevance for LCAs on waste management systems will be discussed. It is suggested that many of these aspects are of relevance also for other types of systems engineering models of waste management systems (Finnveden 1999c). This section is largely based on previous methodological publications (Finnveden 1999c, Clift et al. 2000, Ekvall and Finnveden 2000b, Finnveden 2000b). Aspects that will be discussed include: Upstream and downstream system boundaries, Open-loop recycling allocation, Multi-input allocation, Time especially in relation to landfills, Landfills as a carbon sink, and Life cycle impact assessment.

2.2.1 Upstream and downstream system boundaries

A key aspect of LCA is that the system should be modelled in such a manner so that inputs to and outputs from the system are followed from the “cradle to the grave”, which means that the inputs should be flows that are drawn from the environment without human transformation, and outputs should be flows that are discarded to the environment without subsequent human transformations (ISO 1997). In LCAs of waste management systems, this is typically not done. Instead, the inputs are often solid waste as they appear, e.g. from households. This is, however, still compatible with the LCA definition, if the same inflow appears in all systems which are to be compared. This is because those parts of the systems, which are identical in all systems that are compared, can be disregarded. The upstream system boundary may, however, have to be changed, if one of the systems to be compared produce more or less waste than the others. In this situation the system inputs are no longer identical, and in principle the system boundary should be moved and upstream activities be included, at least those parts which differ between different systems. This may in practise prove to be very difficult and therefore not done. In that case it should, however, be carefully noted that the impacts of the system which produces less waste is overestimated compared to the others.

A similar situation may occur for the downstream system boundary when materials or energy are recycled into new products. In LCAs of waste management systems, products from recycling are normally not followed to the “grave” and neither are the products, which are replaced by the products from recycling. Again this is compatible with the LCA definition, if the products are “identical” in all systems which are compared. In these cases the products can be disregarded. “Identical” does not mean that they have to be exactly identical in all aspects. It is enough if they are providing a comparable function to the user, and if they have the same environmental impacts. If the products are not providing comparable functions, they cannot replace each other. If the products do not have the same environmental impacts, at least the difference should be included in the LCA.

2.2.2 Open-loop recycling

Open-loop recycling takes place when a product is recycled after its use into another product. This can be a problem since the system boundary between products 1 and 2 is not clear-cut. Open-loop recycling has been much discussed in the LCA literature e.g. Huppes and Schneider (1994), Finnveden and Huppes (1995), Lindfors et al. (1995), Udo de Haes and Wrisberg (1997), Ekvall (1999) and Ekvall and Finnveden (2000b). The problem can be solved in two ways: by allocating environmental interventions between the two products and study only one of them, or by expanding system boundaries and including both products within the system.

If allocation is to be made, there are three parts of the system that should be allocated between the two products (Lindfors et al. 1995):

1) the recycling system
2) production of primary material used in both products
3) disposal of materials used in both products

Many methods for the allocation have been suggested in the literature and used in case studies (Huppes and Schneider 1994, Lindfors et al. 1995, Ekvall 1999). There does not seem to be any procedure that proves that any specific method is the “correct” one. Instead arguments are usually based on what intuitively seems reasonable or fair. However, such arguments can lead to very different conclusions and different allocation procedures can lead to different results (Ekvall and Tillman 1997).

In order to avoid the allocation problem, system boundaries can sometimes be expanded to include several functions within the system. An example is the comparison between landfilling and incineration of waste. The main function of landfilling is treatment of solid waste. (In addition landfill gas is sometimes collected and used, but this aspect is however neglected in this methodological discussion). Incineration with heat recovery also treats solid waste, but in addition produces heat or electricity, thus providing a second function (Figure 2.3a). Since the processes provide different functions, it is difficult to directly compare them.

In the expanded system an alternative method of producing an equivalent amount of heat has been added to the landfill system (Figure 2.3.b). It is thus possible to compare the incineration system to the combined landfill and heat producing systems. The systems compared are multi-functional systems. Another way of presenting the expanded systems is to subtract the heat-producing system from the incineration system using an alternative heat-source, as described in Figure 2.3.c. Since the same components are included, it is essentially the same systems which are presented in Figure 2.3.b and 2.3.c. In the system shown in Figure 2.3.c, so called “avoided emissions” will occur and environmental interventions may become negative.

When using system expansion, several functions are studied at the same time. This is not always apparent since the subtracted systems appear as single-functional. When using system expansion it is no longer possible to study one function in isolation. This can be seen as an advantage since this reflects the real situation. In a situation where different functions cannot be chosen independently, it is an advantage if this is reflected in the LCA. For example, if a choice is made to incinerate solid waste with heat recovery, it is no longer possible to choose another energy source and this is illustrated in the expanded system. Also, from another perspective, if solid waste is chosen as the energy source, it is no longer possible to choose another treatment method for solid waste. This illustrates that if solid waste is considered as an energy source, the energy system and waste management system must be considered simultaneously. This also implies that the systems will be identical whether the starting point is the choice of energy source, or the choice of waste treatment.

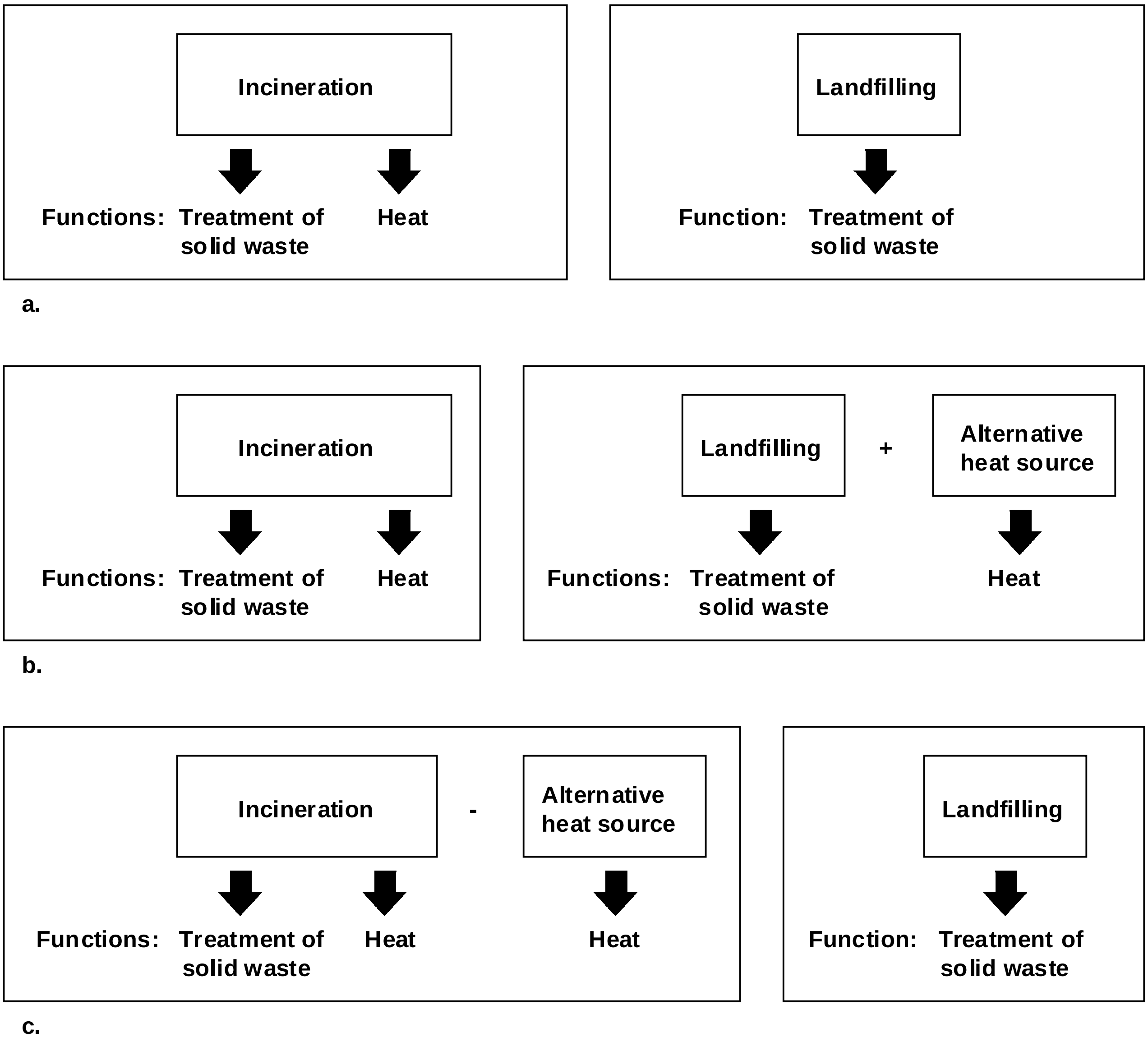

Figure 2.3.a. An example of an allocation problem. b. A possible way of avoiding the allocation problem by expanding the system boundary. c. An alternative way of presenting the expanded system boundary described in figure b. (Finnveden and Ekvall 1998)

The use of expanded system boundaries to avoid the allocation problem is often recommended, for example in the Nordic Guidelines (Lindfors et al. 1995), and the ISO-standard (ISO 1998). The ISO-standard has been critically reviewed, but system expansion is still generally recommended for change-oriented studies, e.g. Tillman (1999) and Ekvall and Finnveden (2000b). There are however some critical questions to consider when using system expansion (Ekvall and Tillman 1997, Ekvall and Finnveden 2000b). For example:

1) What material will the recycled material replace? It is often assumed that the recycled material will replace virgin material of the same kind. For example, recycled paper is

often assumed to replace virgin paper. However, in some cases, recycled paper may replace another type of recycled paper or another material, e.g. plastic.

2) If (more or less) waste is incinerated with heat recovery, what is the alternative energy source? This question is of interest when comparing incineration with heat recovery with other treatment methods. The same applies for other treatment options, anaerobic digestion and landfilling with gas collection, where heat may be generated. In the case of comparing recycling to incineration of paper packaging material, it has been shown that assumptions concerning the alternative energy source can be decisive to the outcome of the study (Finnveden and Ekvall 1998, Ekvall and Finnveden 2000c).
3) Are the demands independent of how the products are produced? It is generally assumed in LCAs that the demands for the functions fulfilled by the systems are independent of how they are fulfilled (Tillman et al. 1994). The system modelled is thus a simplification of the real system.
4) Are the functional qualities of the products and/or material similar and independent of how they are produced? It is often assumed that the recycled material can replace another material having similar functional qualities. If the materials are similar, the processes downstream may be considered as identical and disregarded in a comparative assessment, greatly facilitating the study, as discussed above.

The answers to these and other questions are likely to depend on the goal of the study as briefly discussed in section 2.1.2. Important aspects to consider are for example the time frame for the study and what type of decisions might be based on the analysis.

2.2.3 Multi-input allocation

One type of allocation problem (the case of open-loop recycling) was discussed above. Another type is called the multi-input allocation problem. It occurs when several products are inputs to processes, and it focuses on determining which environmental interventions should be allocated to which products. One example can be emissions of hydrocarbons with landfill gas. Some of these chemicals may be degradation products and some may come from specific products in the waste. The question is how the emissions shall be allocated to the different products and materials in the waste. Another example concerns emissions of chlorinated hydrocarbons from incineration of municipal solid waste.

The guiding principle for the multi-input allocation problem should be the underlying physical, chemical or biological relationships and there is a general agreement in the LCA world on this e.g. Finnveden and Huppes (1995), Lindfors et al. (1995) and ISO (1998). The question then becomes a scientific/technical question of finding the relevant causalities. This in turn may turn out to be dependent on the purpose of the study as briefly discussed above. For example, if the relationships between inputs and emissions are non-linear, the scale of change should influence the allocation.

2.2.4 Time aspects

One important difference between landfilling and most other processes in an LCA is the time frame. Emissions from landfills may prevail for a very long time, often thousands of years or longer. The potential emissions from landfilling have to be integrated over a certain time-period. It is important to determine which time period is of interest. There is currently no international agreement on this question (Finnveden and Huppes 1995). Using the LCA definition as a starting point, it can be argued that emissions should be integrated until infinity. In practise however, a shorter time frame (decades and centuries) has usually been chosen (see Finnveden (1999c) for a review). The choice of the time period can have a significant influence on the results for materials that are persistent (e.g. plastics) and for substances which are only slowly leaching out, e.g. metals from municipal solid waste and ashes (Finnveden 2000b).

The choice of the time frame is clearly a value choice for the inventory analysis of an LCA. It is related to ethical views about impacts on future generations (Finnveden 1997). It is clearly a question that deserves more attention. Important aspects to discuss include the possibilities and consequences of different choices as well as the ethical discussion, which apparently can not be avoided. A similar situation may occur for different parts of the life cycle impact assessment. The choice made by the SETAC-Europe working group on Life cycle impact assessment is to consider first the infinite time period, then a short time period of 100 years and finally if wanted other time periods (Udo de Haes et al. 1999a, Udo de Haes et al. 1999b).

2.2.5 Landfills as carbon sinks

When carbon flows in landfills are modelled, a distinction is often made between biotic (from renewable sources) and non-biotic carbon (from fossil sources). Common practise is to disregard biotic CO_2-emissions. This can be motivated from different perspectives (Dobson 1998). One includes an expansion of the system boundary to include also the uptake of the CO_2 in the growing tree. This expansion is often done as a thought experiment rather than an actual modelling. Another perspective can be the assumption that when biotic resources are harvested, new resources are planted which will take up an equivalent amount of CO_2. Again this modelling is normally not done explicitly. Yet another perspective is the assumption that if the biotic resources, e.g. trees, had not been harvested, they would have been left in the forest and degraded there. This degradation can however be quite slow, and the time frame has to be extended to several centuries before all biotic materials have been degraded (Zetterberg and Hansén 1998).

The practise to disregard biotic CO_2-emissions can lead to erroneous results (Dobson 1998). Let us consider an example to illustrate this. Let us compare incineration and landfilling of a hypothetical product consisting of only cellulose. When incinerated, nearly 100 % of the carbon is emitted as CO_2. However, in the inventory, this emission is often disregarded as noted above. If the product is landfilled, approximately 70 % of the material is expected to be degraded and emitted during a short time period, mainly as CO_2 and CH_4 (Finnveden et al. 1995) (The short time period is here defined as the surveyable time period, which will be explained in 2.3.6). Again the emitted CO_2 is normally disregarded, although the CH_4-emissions are noted. During the surveyable time period, 30 % of the carbon is expected to be trapped in the landfill. There is thus a difference between the landfilling and the incineration alternatives in this respect, in the incineration case all carbon is emitted, whereas in the landfilling case some of the carbon is trapped. This difference is however not noted, since the CO_2-emissions are disregarded and this is in principle a mistake. Additionally, the biological carbon emitted as CH_4 in the landfilling case is noted and will discredit this option. It could be argued that a part of the global warming potential, corresponding to the potential of the same amount of biological carbon in CO_2, should be subtracted from the landfilling inventory.

There are several ways of avoiding these mistakes concerning biological carbon emissions. One is to explicitly include modelling of the processes where there is a CO_2-uptake. If this is done, there is no need to make a differentiation between biotic and non-biotic CO_2. In cases where there is a carbon trap, this will lead to negative CO_2-emissions and no distinction between biological carbon in CH_4 and CO_2 will be made. This solution is the formally correct one and should not lead to any additional mistakes. Another simpler solution is to continue the differentiation between biotic and non-biotic CO_2, but simply attribute a negative CO_2-emission to the trapped carbon.

Another question is whether the carbon trap matters for the final results. For easily degradable materials, the carbon trap will normally only have a minor influence on the results in terms of CO_2-equivalents for a short time period. This is because most of the carbon will be emitted from the landfill and not trapped. For not easily degradable materials, the carbon trap can however be of significant importance for a short time period. Finally, it should again be noted that the carbon trap is only an issue for renewable materials where CO_2-emissions are normally not considered and only when a limited time perspective is used.

2.2.6 Life cycle impact assessment of integrated solid waste management systems

Life cycle impact assessment is the phase of an LCA aimed at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system (ISO 1997). In an LCA it will normally not be known where and when all the emissions take place. This is one of the reasons why LCA cannot predict actual impacts but is restricted to analysing potential impacts (Udo de Haes 1996). When analysing emissions from landfills the situation is enforced since the emissions will occur in a future situation. The emissions cannot be measured but only predicted. A consequence of the predictions is that it is potential emissions rather than actual emissions that can be included in the LCA for landfilling processes. This can make the impact assessment more difficult because there are increased problems modelling background concentrations and other aspects which may be of importance for the impact assessment. There are however, other situations in an LCA where emissions occur on different time scales (Hofstetter 1996), e.g. in LCAs on building materials. The standard solution to this problem is to treat all emissions as if they occur at the same moment. If this is also assumed for landfilling processes, methods that are being used for LCIA in general can also be used for waste management systems.

There is however one additional aspect which relates to the previous discussions: are future impacts more or less important than current impacts? If for example the weighting would be limited to effects within a certain time period, then the specification of emissions after this time period would be unnecessary (Finnveden and Huppes 1995). Also if the weighting placed a different importance on effects occurring at different times, the inventory analysis must indicate the time scale of emissions (Finnveden and Huppes 1995). The principle that future generations should not be burdened with the environmental costs of current activities might involve placing more emphasis on future effects (Finnveden and Huppes 1995). On the other hand, it will for many people seem quite senseless to take into account effects occurring after more than 100 000 or one million years, time scales which may be relevant for some types of waste (Finnveden and Huppes 1995).

The definition of LCA states that the assessment should include the complete life cycle, and there is no restriction in time. This suggests that all emissions should be included, regardless of when they occur. However, if one would like to put a lesser emphasis on future impacts there are two possible solutions:

1) A cut-off after a certain time period. If this approach is used, emissions after a certain time period, and impacts associated with them are completely disregarded. The implicit assumption is that impacts after the chosen time period are of no importance. This is consistent with a view that future generations are of no importance (Finnveden 1997).
2) A discounting is made. The purpose of discounting is to discriminate against the future (Turner et al. 1994). The choice of the discount rate is an ethical and ideological issue

both in relation to the question of how future generations are valued and in relation to expected economic growth (Finnveden 1997).

Discounting is currently not used in LCA. A cut-off is used in the approaches where emissions from landfills are only considered for a certain time period, and the remaining waste is described as inert if considered at all. When using that type of approach, an ethical valuation is implicitly made to place no importance on impact affecting future generations. It is important to realise that when deciding on which time period(s) to consider in an inventory analysis, an ethical valuation is in practise being made.

2.3 Scope and methodological choices made in this study

In this section, some methodological choices made in this study will be described. They will be made in relation to the overall aim and scope of the study, as described in section 1.3. The methodological choices also further define the scope of the study. The methodological issues discussed here have in general been introduced above.

2.3.1 Functional unit

The study includes fractions of municipal solid waste which are combustible and recyclable or compostable, these fractions are presented in chapter 4. The functional unit of the study is treatment of the amount of the included waste fractions collected in Sweden during one year. The amounts are also specified in chapter 4. Results are presented both for the whole system and for specific waste fractions.

2.3.2 Specification of the goal

In section 1.3, the aim of the study was presented and in section 2.1.2, different types of goals were briefly discussed. This study is change-oriented (prospective). We want to analyse the effects of different choices concerning waste management. Ideally the data used should reflect the actual changes taking place, thus some sort of marginal data should be used (this is discussed in section 2.1.2 and further discussed below in chapter 3). The results are intended to be used for strategic decisions including decisions on new investments and policies. The time frame is long (decades) because decisions made today or in the coming years on for example energy systems and waste treatment facilities will have effects several decades into the future. (Please note that “long time-frames” can have very different meanings. When discussing the goal of the study a long time frame means decades. When discussing landfills, decades is a short time frame. A long time frame for landfills means time periods substantially longer than decades.)

2.3.3 Waste materials, treatment methods and the use of scenarios

The waste materials included in this study are fractions of household waste: food waste, newspaper, corrugated board, mixed cardboard, polyethylene, polypropylene, polystyrene, poly(vinyl chloride) and polyethylene terephtalate. This is further discussed in chapter 4.

The treatment methods considered are incineration (of all fractions), landfilling (of all fractions), recycling (of all fractions except food waste), anaerobic digestion (of food waste) and composting (of food waste). The biogas produced from anaerobic digestion is either used as fuel replacing diesel or for production of heat and electricity. The calculations are made for the unrealistic condition that all waste is treated with the same treatment method. This is done in order to facilitate the comparisons. Results are presented for each waste fraction and for the whole system. For the whole system, recycling is combined with either anaerobic digestion or composting of the food waste. Source separation is assumed as a part of the recycling strategies. Also incineration may be combined with source separation. This can be of interest in integrated strategies where for example some fractions are recycled whereas others are incinerated.

In the study we have defined a base scenario. In order to better understand what factors in the studied systems and which assumptions that are most critical we have performed the calculations for a number of different “what-if scenarios”. These are used to study what happens if certain assumptions are changed. The extensive use of “what-if scenarios” can be regarded as a sensitivity analysis of the studied system. The base scenario and the “what-if scenarios” are collectively called scenarios in this report. The scenarios are described in more detail in chapter 3, but some aspects are outlined below.

2.3.4 System boundaries

The study is an LCA and this implies that ideally all inflows should be traced back to the system boundary between the environment and the technosphere, and all outflows should be traced to the point where emissions leave the technosphere. This has been the general ambition but there are of course several exceptions to these rules:

- The waste is taken as the input to the system and not followed upstream. This is compatible with the LCA definition since equal amounts of waste of the same composition are treated in all systems.
- Materials which are assumed to replace each other, e.g. recycled plastics replacing plastics produced from virgin materials are not followed downstream. This is compatible with the LCA definition if the properties are identical. This is a problem for some paper fractions where the recycled material is somewhat heavier than the material produced from virgin materials. This is further discussed in chapter 5.
- In the case of forestry, the wood and biofuels are taken as inputs to the technosphere.
- Additives and auxiliary materials are included whenever data has been available. In some cases however, upstream data on additives and auxiliary materials has not been available. In these cases it is noted in the description of the different processes in section 5.
- Landfilling of waste is in principle included. This is the case for all wastes being inflows in this study, ashes from incineration of waste, and sludge from wastewater treatment of leachates from landfilling of waste and drainage water from composting. There is however a number of different types of process wastes from other processes in the systems where treatment of waste is not included. Such types of waste are noted in section 5 and also included in the results as non-treated waste.
- There are of course different types of data gaps, inflows and outflows that are unknown to us and therefore not included. Below it is discussed which impact categories we believe are reasonably well covered and for which there are significant datagaps.
- Capital equipment is in general not included in the study. As a rule of thumb, capital equipment for heat and electricity generation, requires a tenth of the environmental impacts compared to the overall life-cycle as for example recently described by (Otoma et al. 1997) for municipal solid waste incinerators.

System boundaries related to time in the case of landfills and system boundaries in the case of open-loop recycling are discussed below.

2.3.5 Open-loop recycling

When useful products are produced from the waste treatment systems we have used the system expansion approach for avoiding the open-loop allocation. Mainly due to practical reasons in relation to the LCA software programme we are using (Sima Pro 4.0 described in section 2.4) we have used subtracted systems resulting in avoided burdens. The systems we are studying therefore have only one functional unit, described above in section 2.3.1, but several functions which are not leaving the system. For each waste treatment method there is one or several functions which are avoided. These match the functions the treatment methods are providing in addition to the function of taking care of the waste. Exactly how this is done is described in chapter 5 when describing the processes and in chapter 3 when describing and motivating the scenarios we are looking at. However, since it has been shown earlier (e.g. in the case of waste management of paper (Finnveden and Ekvall 1998, Ekvall and Finnveden 2000c)) that the choice of the avoided function can have a decisive influence on the results, it will be briefly described also here:

- Heat from solid waste incineration and incineration of landfill gas and biogas from anaerobic digestion is assumed to replace heat produced from other sources which are varied. In the base scenario biofuels are used, and in two alternative scenarios, natural gas is assumed.
- Electricity produced from incineration of landfill gas and biogas is assumed to replace electricity from coal-fired power plants as a marginal source of electricity.
- Fuel produced from biogas is assumed to replace diesel fuel.
- Recycled paper is assumed to replace paper materials of similar qualities made from virgin materials.
- Recycled plastics are in the base scenario assumed to replace plastics of the same kind produced from virgin raw materials. In one scenario however, recycled mixed plastic waste is assumed to replace impregnated wood used in palisades.
- Residues from anaerobic digestion and composting are replacing artificial fertilisers with similar contents of nitrogen and phosphorous.

2.3.6 Time aspects in the case of landfills

We have in our work used two time-perspectives (Finnveden 1992, Sundqvist et al. 1994, Finnveden et al. 1995, Finnveden 1996, Sundqvist et al. 1997):

1) "The surveyable time period", which is defined as the time period it takes to reach a pseudo steady state in the landfill. The surveyable time period should correspond to approximately one century. In this case the time period is defined by the processes in the landfill. For municipal solid waste landfills, the surveyable time period is defined as the time it takes to reach the later part of the methane phase when gas production is diminishing. For some types of solid wastes, it may be difficult to define a pseudo steady state within this time frame. In such cases 100 years is used as default.
2) "The hypothetical infinite time period" is defined by total degradation and emission of the landfilled materials. This time period is introduced to get the maximum, potential impacts. This time period is split into the surveyable time period (ST) and the remaining time period (RT) in order to facilitate the inventory analysis.

In the base scenario we have used the hypothetical infinite time period. In two scenarios we have used the surveyable time period.

2.3.7 Landfills as a carbon sink

In the base scenario landfills are not modelled as carbon sinks since this is only of interest for shorter time periods (section 2.2.5). However, in one of the scenarios where the surveyable time period is used, landfills are modelled as carbon sinks. How this is done is described in detail in chapters 3 and 5.

2.3.8 Life Cycle Impact Assessment

Table 2.2 describes the impact categories, which are considered in this study, and they are further discussed below. Also noted are the extent to which we believe there are significant datagaps or not. Also included is an approximation of the uncertainties involved which are discussed and explained below in section 2.3.9.

Table 2.2. List of impact categories included in this study.

Impact category	Significant datagaps?	Estimated uncertainties involved, as a factor
Total energy	No	2
Non-renewable energy	No	2
Abiotic resources	No	2
Non-treated waste	Yes	100
Global warming	No	10
Depletion of stratospheric ozone	Yes	1000
Photo-oxidant formation	Yes	10
Acidification excluding SO_x and NO_x	Yes	10
Aquatic eutrophication excluding NO_x	Yes	100
SO_x	No	10
NO_x	No	10
NH_3	Yes	100
Eco-toxicological impacts	Yes	1000
Human toxicological impacts	Yes	1000

The list of impact categories included in this study is similar to the default list of impact categories presented in Table 2.1 but not identical. The major differences are discussed below.

- Because the study has a background with focus on energy systems, it is useful to include the total energy and non-renewable energy as separate impact categories. The renewable energy can easily be calculated from the difference between the total and the non-renewable energy. In the energy categories, all inputs that could be used as a fuel are included regardless if they actually are used as fuels or as raw materials.
- Abiotic stock resources are included in a separate impact category. Biotic resources are not included as a separate impact category but the interested reader can approximate biotic resources with renewable energy since most of the renewable energy comes from biomass.
- Partly for practical reasons in relation to the weighting method used, emissions of SO_x and NO_x are presented separately and the impact categories acidification and aquatic eutrophication are presented excluding emissions of SO_x and NO_x.
- Non-treated waste is an impact category including flows, which have not been followed to the grave.
- Ecotoxicological and human toxicological impacts are further divided into subcategories depending on the characterisation method used as discussed in section 6.
- Land, odour, noise, radiation and casualties are not included in this study.

Not all impact categories are equally well covered in this study. We believe that the total energy, non-renewable energy, abiotic resources, global warming, SO_x and NO_x impact categories are reasonably well covered without significant datagaps. The other impact categories will however probably have datagaps, which can be significant, and conclusions regarding these impact categories, and also total weighted results, should therefore be done cautiously.

It can be noted that both the choice of impact categories and the extent of data gaps are quite similar to most other LCAs (Finnveden 2000a).

In this study both characterisation and weighting elements are included and results from these steps are reported. The methodologies used for characterisation and weighting is further described in chapter 6.

2.3.9 Data quality and uncertainty

LCA is an iterative process. The learnings from earlier studies should be used when performing new studies. We have based this study on results and experiences from earlier studies on waste management systems, for example on paper waste summarised in (Finnveden and Ekvall 1998, Ekvall and Finnveden 2000c). We have within the project performed several rounds of iterations which to some extent have been published (Lind 1999), but largely not. The results presented here thus represent the results after a number of iterations and can be used as inputs to new studies.

Because LCA is an iterative process it is often useful to start with easily accessible data, perhaps with limited quality and then refine the data quality in relation to the importance for the results. In LCAs, large amounts of data are needed. Some of these will be of importance for the overall results, whereas others are of limited or no importance. For the latter type of data, there is no point in putting in resources for finding data with good quality. Data uncertainties in LCA can be quite large. The uncertainties can be of different types e.g. Huijbregts (1998). Some are related to the uncertainty and precision of the data. Some are related to uncertainties in the choice of technologies and LCA methodology. Uncertainties in relation to choices of technology and LCA methodology are often larger than uncertainties in data. It is for example, more important to know if a fuel used is a biofuel or a fossil fuel, than to have emission factors with good quality of either.

This study is change-oriented with a time-perspective of several decades. We do not have access to relevant data for such long time-periods. We are therefore mainly using data for the current situation. Some aspects, for example concerning the surrounding energy systems, are inherently uncertain. We therefore think it is more interesting to try different assumptions in order to find aspects, which are critical for the results, than to put in resources to find better data for the current situation.

Since the study is change-oriented, the ideal data should be data for the processes that actually are affected, which in general would correspond to a base load marginal type of data (Weidema et al. 1999a). For electricity production and heat generation we know that the environmental impacts vary significantly between different energy sources and also that the choice can have a significant influence on the final results for a waste management LCA (e.g. (Finnveden and Ekvall 1998, Ekvall and Finnveden 2000c)). In this study we have therefore tried to assess which energy sources are relevant from this perspective and this is discussed in chapter 3. For other areas, we are mainly using average type of data, which are accessible in LCA databases.

We have used a number of different data sources, and they are all described in detail in section 4 and appendices. Some key references are: Björklund (1998) (incineration and landfilling), Baumann et al. (1993) (recycling of newspaper), Sundqvist et al. (2000) (recycling of mixed cardboard and PE), FEFCO et al (1997) (recycling of cardboard), Person et al (1998) (recycling of PET), Heyde and Kremer (1999) (recycling of mixed plastics), Nilsson (1997) (composting and anaerobic digestion), Uppenberg et al. (1999) (fuels), Frees and Weidema (1998) (electricity and transports). In addition we have used several databases in Sima Pro 4.0 described in section 2.4.1.

In order to facilitate the interpretation of the results we have estimated uncertainties in the data used and the results for different impact categories, Table 2.2. These estimations are based on previous publications on rules-of-thumb for data uncertainties (Lindfors et al. 1995, Finnveden and Lindfors 1998). It can be noted that the uncertainties in the input categories (total energy, non-renewable energy and abiotic resources) are lower and it may be easier to base conclusions on these categories. Some comments concerning the estimated uncertainties can be made. The uncertainties for the input categories are the same as the rule of thumb for central, non-substitutable resources (Finnveden and Lindfors 1998). The rule-of thumb for energy related air emissions is one order of magnitude (Finnveden and Lindfors 1998). We suggest this number for several impact categories associated with air emissions. For other process-specific emissions, the rule-of-thumb suggests a variation of one to two orders of magnitude or larger if mistakes or very different technologies can appear. We suggest a factor of 100 in most cases and a factor of 1000 for some impact categories where large uncertainties and data gaps can be expected.

2.4 The LCA-model in Sima Pro 4.0

In this study the program Sima Pro 4.0 (PRé 1999b) is used. A brief presentation of the program is given here. For a more thorough description, the reader is referred to the available documentation of the program (PRé 1999a, b, c)

2.4.1 Methodology and inventory

Sima Pro 4.0 (SP) is a product related software based on LCA-methodology. The programme is produced by the Dutch company PRé Consultants B.V. The inventory data records consist of different input and output categories. The inputs to a process can be divided in two types:

- Inputs of resources from the environment, the biosphere.
- Inputs of products or semi-finished products to the technical system or the technosphere, which are outputs from other processes

Similarly, there are two types of outputs:

- Outputs of air or waterborne emissions, emissions to soil and solid or non-material emissions to the biosphere.
- Outputs of a product or semi-finished product, which could be input to another technical system or output to the biosphere.

To document these flows for a process in SP, a process data record is used. The process data record is based on the SPOLD (Society for Promotion Of Life-cycle Assessment Development) format. The aim with the SPOLD format is to, in a standardised way, document and present inventory data. This makes its possible to exchange data between users of this format. In the process record it is also possible to make the methodological choice between allocation or avoided production (subtracted system). The SP process data records used in the inventory of this study are presented in Appendix 5.

The standard version of SP includes the databases BUWAL 250 (BUWAL 1998), IDEMAT database (Remmerswaal 1996) and PRé 4 database (PRé 1999c). The program has been supplemented with the commercially available databases FRANKLIN US LCI database (Franklin 1998) and IVAM 2.0 database (IVAM 1998). To these databases we have added data from different sources as briefly described in section 2.3 and in more detail in chapter 5. Collected and complemented data for this study could technically also be available in a future database.

When constructing a process data record in SP there is a menu of different process categories to choose between. They are materials, energy, transports, processing, use, waste scenarios and waste treatment. Since the program is product related, there is flexibility to a certain degree to construct a transparent and flexible Integrated Solid Waste Management model. Process data records in the material category are used to document and model the included scenarios of this study. In these data records the amounts of the included waste fractions are documented and the treatment process used. The treatment processes are documented in the waste treatment category.

2.4.2 Impact assessment

SP includes a number of methods for life cycle impact assessment. Among these we have only used Eco-indicator 99 (Goedkoop and Spriensma 1999). In addition we have added a number of different characterisation and weighting methods as described in chapter 6.

2.4.3 Result presentation

The inventory results for the system in alternative scenarios are presented in SP in an inventory table. The total inventory result for the system is presented but also the contribution from each sub-process separately.

The total result from each of the sub-steps of the impact assessment can be viewed aggregated together or as the contribution from each substance to a specific impact category.

3 Scenarios and major assumptions

3.1 Introduction

In this chapter some major assumptions are described and motivated and the different scenarios are described. A base scenario is defined for the system. The "what-if–scenarios" are used to identify which parameters that may significantly influence and change the outcome of the study. Parameters that are changed include transport distances, time perspective, etc. At the end of the chapter a summary of the scenarios and their characteristics is gathered.

Short descriptions regarding data used for different processes in the system under study recorded by us are found in chapter 5, and short presentations concerning the origin of other data can be found in Appendix 1. In Appendix 5 the full inventory data records for all data used are compiled.

3.2 Electricity production

In this prospective LCA study, base-load marginal data are the ideal data as discussed in section 2.1.2 and 2.3.2. Different sources of electricity can be argued to be generated at the base-load marginal. Weidema et al. (1999b) discusses the long-term, base-load marginal for the European electricity market. They state that the trend for electricity use in Europe is increasing and that the marginal technology thus would be the most preferred technology, which they define as the unconstrained technology with the lowest long-term production costs. This is because when new investments are made, this is the technology that will be used. Their conclusion is that hard coal is the EU marginal power source. If the EU market is considered to still be fragmentised an exception is added for the Nordic countries, where natural gas power is on the marginal due to efforts to lower emission levels. Additionally, wind power is suggested as a potential marginal technology in the future, but with a current constraint due to lack of technical knowledge. Looking at the marginal electricity technology in a shorter perspective, considering existing capacity, hard coal may also be seen as relevant when the European deregulated market is considered.

The discussion of marginal electricity technology in Weidema et al is based on Ekvall et al. (1998). Ekvall et al. discuss a further fragmentation of the northern European electricity market by pointing out the possibility of a delay in the politically decided phasing out of nuclear power in Sweden. They thus suggest that the long-term marginal electricity in Sweden may for some years be generated from some kind of mixture between nuclear and fossil-based sources.

Another way of handling the discussion about which the future electricity on the marginal will be is to assume that the aim is towards a sustainable way of life. With this assumption a decrease in electricity use will probably have to be achieved. With this future trend, the least preferred technology, then also including environmental aspects, will be the marginal technology. This is because when old plants are closed, the least preferred technology will be outphased first. Also in this case it can be argued that coal fired power plants are the base load marginal electricity source.

In this study, electricity generated from hard coal is chosen as the marginal technology. The data for electricity produced from hard coal is from Frees and Weidema (1998), these data are further described in section 5.7. As discussed above other alternatives may also be considered and this should preferably be done in a continuation of this study.

3.3 Heat production

3.3.1 Heat source

In this study heat produced when handling waste by incineration, anaerobic digestion or landfilling is credited the waste treatment option by subtracting heat produced from another source (avoided product systems are explained in chapter 2). Heat produced through the waste management is assumed to be transferred to the district heating system. The 1998 composition of energy carriers contributing to the 44.1 TWh heat delivered by the district heating facilities in Sweden are shown in Table 3.1. As can be seen the major contribution is from forest fuels, this amount has increased by four times since 1990. The main forest fuels are forest felling residues and by-products from the forest industries (Energimyndigheten 1999).

Table 3.1 Energy supplied from different sources to the district heating system in Sweden during 1998 (Energimyndigheten 1999).

Fuel	**Energy supply (TWh)**
Forest fuels	14.7
Heat pumps	7.4
Oil	5.5
Waste	5.0
Surplus heat etc	3.6
Coal	3.4
Natural gas and liquefied petroleum gas	3.3
Peat	3.1
Other biofuels	2.9
Electric boilers	1.8

In this study, the ideal data would be the long-term base load marginal as discussed in 2.1.2 and 2.3.2. Which source this is may be discussed. One key assumption is whether the market for district heating has an up- or down-going trend. If there is an increasing use, the most preferred alternative would be on the marginal and if the use is decreasing the least preferred alternative would instead be defined as the marginal technology. Increasing the district-heating share of the total heating may be considered to be in line with aiming towards sustainable energy use. Transforming systems where electricity is used for heating buildings to being supplied with district heating is one example.

Assuming an upward trend, the discussion may be that biofuels are preferred from a greenhouse effect perspective and that the availability in Sweden is comparably high. On the other hand, on the global market, biomass will become increasingly scarce and also in Sweden different uses for biomass compete for the available resources.

Incineration of waste is another possible marginal heat producing technology if other options of handling this waste is not considered to be significantly more preferable and the amount of combustible waste is sufficient. The waste may be household waste or waste from other sectors, e.g. the building sector. It has been noted that other types of waste is the competing heat source in Sweden today (ÅF-IPK 1998). This is because the current waste incineration capacity in Sweden is limited. If a choice leads to increased or decreased incineration of a specific waste fraction, this is likely to decrease or increase the incineration of other waste fractions and an increase or decrease of landfilling of this fraction resulting in a constant use of the incinerator capacity. If, however, the decision is whether to increase the incineration capacity, the competing heat source is not waste but something else. For the purpose of this study, waste does therefore not seem to be the alternative heat source.

Natural gas is not used to any larger extent in the Swedish district heating system. The extension of pipelines is limited covering parts of southwestern Sweden. There has been some discussion about new natural gas pipelines in Sweden. Energimyndigheten (1999) refers to two studies made concerning gas pipelines connecting the Russian gas grid with the western European. If these kinds of plans come true, natural gas may also be a potential heat source on the marginal.

In this study, two alternative marginal district heating sources are used. The first, used in the base scenario, is forest residues and the second, used in two alternative scenarios, is natural gas. Data used for both these processes are described in section 5.9.

3.3.2 Ashes

Ashes formed when incinerating forest residues are assumed to be brought back and spread in the forest. This is done to retrieve nutrients and trace elements removed with the wood and residues previously extracted. This way metals contained in the residues are also retrieved and they are in the base scenario modelled as emissions to soil occurring subsequent to the surveyable time period (after the first 100 years). In one of the scenarios the ashes are neglected to see how large the impact of these metals is for the system.

3.3.3 Forest saved when recycling paper products

When paper products are recycled, less biomass is used for production of virgin paper materials. This biomass can be left in the forests, but it can also be used for other purposes, e.g. for heat production. If forest fuels are limited, the demand for using the “saved” biomass may increase.

In the base scenario of this study we have assumed that the “saved” biomass is left in the forest. In one scenario we have however assumed that the “saved” biomass is used as fuel for heat production replacing natural gas.

3.4 Transport

In this section the distances for waste collection transports are presented. In Sweden there are geographical differences that have to be considered when modelling a waste collection system. In the north, large areas are sparsely populated and the distance to different waste treatment facilities may be considerable. In the southern parts more waste is produced in smaller regions making it more likely that transport distances are shorter. In the base scenario, the transport distances modelled are short and no passenger car transport is allocated to the transport of household waste to collection points. Two additional scenarios concerning medium and long distance transport of waste by truck are tried, as well as one scenario where the medium truck transport assumption is combined with passenger car transport of waste from the households for the recycling and incineration options.

Source separation of the waste is assumed for recycling but it may also be applied for incineration. This is in line with the possible development towards separate incineration of different waste fractions for better efficiency and also for facilitating small-scale and co-incineration, even though these incineration techniques are not specifically modelled here.

This is also the reason for why extra transportation by passenger car to collection points is a parameter tried for both recycling and incineration to evaluate the possible effects on the results of this activity. In the scenario where this is modelled incineration without passenger car transport is also included for comparison. It is assumed that source separated waste is not collected at the house, but at collection points.

The collection system starts when the waste leaves the household. The steps in the transport chain from that point will further on be described for the different treatment options respectively. The data for different vehicles used are described in section 5.8. Transport distances and type of vehicle used in the scenarios are presented in Table 3.2-4. The distances are based mainly on own assumptions. As an inspiration, transport distances for Uppsala are used in the base scenario (Sundqvist et al. 2000, appendix 2), and transport distances for a rural municipality in the middle of Sweden for the long transports scenario using information on actual treatment sites whenever possible.

The different transport scenarios are:

1) The base scenario with short distances
2) The medium transports scenario
3) The medium transports + passenger car scenario with medium distances for transports by truck and transport by passenger car from the household to the collection point in the recycling, digestion, composting and incineration options.
4) The long transports scenario where the distances for the recycling options are further increased. For the other options the assumptions are generally the same as in 2).

In all the transport scenarios and for all waste management options an energy use of 0.134 MJ/kg waste is included for the first waste collection step. This figure is obtained from Sonesson (1997) and corresponds to the fuel consumption during a waste collection route in the city of Uppsala. Collection routes and the work connected are not the same for collection of source separated waste from collection points and for collection of mixed waste at the house. In the case of source separation and collection points the stops are fewer and the distance travelled to fill the truck may be shorter than in the case of collection at the house. The inclusion of 0.134 MJ/kg waste for all management options is consequently an overestimation for recycling and also for incineration assuming source separation.

Recycling

In the *base scenario* the waste is, in the recycling cases, assumed to be collected at a collection point close to the household, using a garbage truck. No transport by vehicle to the collection point is assumed. Thereafter the waste is transported by a garbage truck 9 km to a reloading point, plus 9 km empty return. From the reloading point to the recycling facility, the distances assumed differ between the different waste fractions and they are presented in Table 3.2.

In the *medium transports scenario* the distance from collection point to reloading point is increased to 100 km, plus 100 km empty return, and the distances therefrom to the recycling facility are also increased as can be seen in Table 3.3.

The same distances as in the previous scenario are used in the third scenario, *medium transports + passenger car*, with the addition of 1 km extra transport by passenger to leave the waste at the collection point.

Finally, in the *long transport scenario* the distances by truck from reloading to recycling facility are doubled compared to the previous, the figures are shown in Table 3.4. No passenger car transport is included.

In the cases where reject from recycling is incinerated transport of the reject from the recycling facility to the incineration plant and of the ashes from the incineration plant to the landfill site are assumed to be performed by truck. The distances can be seen in Table 3.2-4. The distances to the incineration plant vary between fractions within the scenarios, this is assumed not to be of importance for the final outcome, since these distances are minor and the amounts transported small, compared to the long-distance transports of the larger amounts of the waste fractions.

In the scenario where *mixed plastics are recycled into palisades* replacing impregnated wood the transport distances for the plastics waste are 9 km from collection point, plus 9 km empty return and 190 km from reloading point to treatment facility, plus 190 km empty return. Transport of rejects and waste palisades (both plastic and wooden) after use to the incineration plant is 10 km, plus 10 km empty return. Transportation of ashes from the incineration plant to a landfill is assumed to be 6.5 km, plus 6.5 km empty return.

Digestion and Composting

The collection and transportation of food waste for digestion and composting also starts with the collection of waste by a garbage truck. In the *base scenario* the waste is thereafter transported 20 km to the digestion or composting plant, plus 20 km empty return. Digestion or compost residues produced are driven 5 km to the fields, plus 5 km empty return (Table 3.2).

In the *medium transport scenario* the distances are 250 km to the digestion or composting plant, plus 250 km empty return, and 10 km for the residues to the field, plus 10 km empty return (Table 3.3).

The same distances as the previous are used in the third scenario, *medium transport + passenger car*, with the addition of 1 km extra transport by passenger car to leave the food waste at the collection point (Table 3.3).

In the *long transports scenario* the distance to the field is assumed to be 20 km, plus 20 km empty return, other distances are the same as in the medium transports scenario (Table 3.4).

Incineration

After the collection by garbage truck the waste is, in the *base scenario* for incineration, assumed to be transported 20 km to reach the incineration plant, plus 20 km empty return (Table 3.2). In the *medium transport scenario* this distance is increased to 250 km, plus 250 km empty return (Table 3.3).

1 km extra transport by passenger car is assumed to precede the garbage truck collection at the collection point in the scenario *medium transport + passenger car* (Table 3.3).

Ashes remaining after incineration are assumed to be transported 6.5 km, plus 6.5 km empty return, to a landfill site in all scenarios except the *long transports scenario*, where it is doubled. The same transport distances as in the medium transports scenario is else used also in the long transport scenario (Table 3.4).

Landfill

As in the other options a garbage truck first collects the waste at the households for landfilling. Following, the waste is transported 15 km, plus 15 km empty return, in the *base scenario* and 150 km, plus 150 km empty return, in the *medium transports scenario* to reach the landfill site. In the two other scenarios no alterations are made in the landfill option, the data of the medium transport scenario is kept.

Table 3.2 Vehicles and distances within the collection and transportation system of the treatment options in the base scenario. The figures are in km except for the collection with garbage truck, which is in MJ/kg. All distances are one way, and in the modelling empty return is included. Figures not marked with a note are own assumptions, in some cases extrapolated from the sources within the same column.

ACTIVITY	Collection	Collection Point to Reloading Point	Reloading Point to Treatment Facility	Collection Point to Treatment Facility	Reject to Incineration	Ashes to Landfill	Residues to Field
VEHICLE	Garbage truck	Garbage truck	Truck	Garbage truck	Truck	Truck	Truck
Recycling newspaper	0.134	9	50				
Recycling corrugated cardboard	0.134	9	250				
Recycling mixed cardboard	0.134	9[1]	100			6.5	
Recycling PE	0.134	9[1]	190		4.5	6.5	
Recycling PP	0.134	9	190		10	6.5	
Recycling PS	0.134	9	190		10	6.5	
Recycling PET	0.134	9	750				
Recycling PVC	0.134	9	190		10	6.5	
Digestion	0.134			20			5
Composting	0.134			20			5
Incineration	0.134			20[1]		6.5	
Landfill	0.134			15[2]			

[1] (Sundqvist et al. 2000Appendix 2). Average value from case studies in Uppsala

[2] (Tillman et al. 1991)

Table 3.3 Vehicles and distances within the collection and transportation system of the treatment options in the medium transports and the medium transports + passenger car scenarios. The difference between these two is only the addition of car transport for some options. The figures are in km except for the collection with garbage truck, which is in MJ/kg. All distances are one way, and in the modelling empty return is included. Figures not marked with a note are own assumptions, in some cases extrapolated from the sources within the same column.

ACTIVITY	Household to Collection Point	Collection	Collection Point to Reloading Point	Reloading Point to Treatment Facility	Collection Point to Treatment Facility	Reject to Incineration	Ashes to Landfill	Residues to Field
VEHICLE	Car	Garbage truck	Garbage truck	Truck	Garbage truck	Truck	Truck	Truck
Recycling newspaper	0.5	0.134	100	200				
Recycling corrugated cardboard	0.5	0.134	100	400				
Recycling mixed cardboard	0.5	0.134	100	250			6.5	
Recycling PE	0.5	0.134	100	250		4.5	6.5	
Recycling PP	0.5	0.134	100	250		10	6.5	
Recycling PS	0.5	0.134	100	250		10	6.5	
Recycling PET	0.5	0.134	100	1000				
Recycling PVC	0.5	0.134	100	250		10	6.5	
Digestion	0.5	0.134			250			10
Composting	0.5	0.134			250			10
Incineration	0.5	0.134			250		6.5	
Landfill		0.134			150			

Table 3.4 Vehicles and distances within the collection and transportation system of the treatment options in the long transports scenario. The figures are in km except for the collection with garbage truck, which is in MJ/kg. All distances are one way, and in the modelling empty return is included. Figures not marked with a note are own assumptions, in some cases extrapolated from the sources within the same column.

ACTIVITY	Collection	Collection Point to Reloading Point	Reloading Point to Treatment Facility	Collection Point to Treatment Facility	Reject to Incineration	Ashes to Landfill	Residues to Field
VEHICLE	Garbage truck	Garbage truck	Truck	Garbage truck	Truck	Truck	Truck
Recycling newspaper	0.134	100	400				
Recycling corrugated cardboard	0.134	100	800				
Recycling mixed cardboard	0.134	100	500			13	
Recycling PE	0.134	100	500		9	13	
Recycling PP	0.134	100	500		20	13	
Recycling PS	0.134	100	500		20	13	
Recycling PET	0.134	100	2000				
Recycling PVC	0.134	100	500		20	13	
Digestion	0.134			250			20
Composting	0.134			250			20
Incineration	0.134			250		13	
Landfill	0.134			150			

All distances presented in Tables 3.2-4 are one-way. In the case of the garbage truck the empty return journey is included in the energy factor used (Sonesson 1997). For the truck this is not the case. Instead of modelling the empty return, the distance is doubled in the model and the energy use for 50% load is used as an approximation. Waste transports by truck are modelled as transport work, using the distance travelled and the wet weight of the waste transported. This allocation by mass includes an uncertainty, since the approach does not take the volume of the waste into consideration, which may be important for bulky waste materials, e.g. some plastic fractions. In the scenario where a passenger car is used to transport the waste to the collection point, this transport is completely allocated to waste handling. This 1 km extra transport is assumed to be performed for each kg of waste, using the wet weight figures.

3.5 Landfill modelling

3.5.1 Scenario Surveyable Time period (ST)

When modelling landfills, boundaries in time may be set differently. Here the definitions surveyable time period (ST) and remaining time period (RT) are used (for an explanation of the expressions see chapter 2). Most often in current life cycle assessments the time span under study is delimited to a shorter time period (Finnveden 1999c), which usually is about 100 years – a cut-off is made. In the base scenario of this study we use a hypothetical infinite time period (ST+RT), which may be defined as a worst case. In two scenarios all emissions occurring later than the surveyable time period are omitted from the assessment. This is done to illuminate how assumptions concerning boundaries in time may affect the results.

3.5.2 Scenario ST + Carbon Sink

When only studying the surveyable time period one may also consider the biological carbon remaining in the landfill after this period has passed as avoided emissions of greenhouse gases as discussed in chapter 2.2.5. Since the biological carbon is part of a carbon cycle in current time, any withdrawal of carbon from this cycle may be credited as avoided emissions. The landfill may then be considered as a so called carbon sink. This is here performed by inventorying the biological carbon remaining in the landfill after the surveyable time period has passed as negative emissions of CO_2. However, this is only applicable if the time frame is limited.

3.6 Scenario Plastic Palisade

When recycling thermo plastics the material is re-melted and the re-granulate may be used for production of new plastic products, usually carrier bags, refuse sacks and packaging not to be used for food stuff, etc. (Naturvårdsverket 1997, p 36). Collected plastics that are mixed and/or very dirty may be recycled without extensive sorting and washing previous to the process. Plastics recycled may also be used for producing ”profiles” ending up as noise barriers, composting containers or poles often replacing impregnated wood. In this scenario palisades made from recycled mixed plastics are studied and assumed to replace palisades from impregnated wood.

3.7 Qualitative discussions

The impacts of a couple of aspects have been qualitatively discussed. These are the assumed degree of efficiency at incineration plants and the characterisation of metals and heavy metals as grouped emissions. The first aspect is an example of how technology assumptions may be of importance. The other one shows upon the dilemma of undetailed inventories, where emissions or resources may be aggregated leading to extra difficulties in assessing the resource use and environmental impacts.

3.8 Additional time perspectives on global warming

The gases contributing to global warming have different life times in the atmosphere. Global warming potentials (GWP) used in the characterisation of global warming may therefore be calculated for different time frames. The International Panel on Climate Change provides global warming potentials for 20, 100 and 500 years (Houghton et al. 1996). In the base scenario we use those for the time frame 100 years. In one scenario the calculations in the base scenario are compared with calculations using the time frames 20 and 500 years. This is expected to mainly affect landfilling where substantial emissions of methane occur. The GWP for methane varies from 56 CO_2-equivalents over a 20 year perspective, to 21 in a 100 year perspective and 6.5 in a 500 year perspective. The results may however also be influenced by the GWP of nitrous oxide, which is 280 CO_2-equivalents in the 20 year perspective, 310 in the 100 year perspective and 170 in the 500 year perspective. The GWPs for the different time frames can be found in Appendix 2.

3.9 Summary of the scenarios

Some of the features of the different scenarios are summarised below.

3.9.1 Base Scenario

The transport distances are in the base scenario short and there are no transports by private cars. The avoided heat is from forest residues. The ashes from incineration of forest residues are spread in the forest. The ”saved” forest from recycling of paper is left in the forest. The time period considered for landfills are long corresponding to the ”hypothetical infinite time period”. Recycled materials are assumed to replace virgin materials of the same kind. Electricity is produced from a modern coal condensing power plant.

3.9.2 Medium transports scenario

The medium transports scenario is identical to the base scenario except that the transport distances related to the waste management are increased to a medium degree, as described in section 3.4.

3.9.3 Long transports scenario

In the long transports scenario the transports by truck are increased further as described in section 3.4, mainly for the transport of waste to recycling facilities.

3.9.4 Medium transport plus transport by passenger car

The scenario medium transports plus transports by passenger cars is identical to the medium transports scenario except that some transports of waste materials are assumed to be made by private cars as described in section 3.4.

3.9.5 Natural gas scenario

The natural gas scenario is identical to the base scenario except that the avoided heat is assumed to be produced from natural gas.

3.9.6 Saved forest scenario

The saved forest scenario is identical to the previous except that the ”saved” forest from paper recycling is used as a fuel replacing natural gas.

3.9.7 Surveyable time period scenario

The surveyable time period scenario is identical to the base scenario except that only a shorter time period (the surveyable time period) is considered. This affects landfills and emissions from ashes retrieved to the forest after incineration of forest residues.

3.9.8 ST + Carbon sink scenario

The carbon sink scenario is identical to the surveyable time period scenario except that the landfill is modelled as a carbon sink for renewable materials.

3.9.9 Plastic palisade scenario

The plastic palisade scenario is identical to the base scenario except that mixed plastics are assumed to be recycled into palisades which replace wooden palisades impregnated with copper compounds. Only the plastic fractions are looked upon.

3.9.10 Excluding metals in ashes from biofuels scenario

The excluding metals in ashes from biofuels scenario is identical to the base scenario except that metals in the ashes from incineration of forest residues are disregarded from the assessment.

3.9.11 Qualitative discussion on degree of efficiency for incineration plants

Here it is qualitatively discussed how different assumptions regarding energy efficiency can influence the assessment.

3.9.12 Qualitative discussion on characterisation of metals

Here it is qualitatively discussed how different characterisations of metal emissions, which have been inventoried as an aggregate, can affect the assessment.

3.9.13 Additional time perspectives on global warming

Different time frames, 20 and 500 years, for the characterisation of global warming impact is tested. In the base scenario the 100 years time frame is used.

4 Household waste composition

4.1 Introduction

In this chapter the waste composition modelled will be described as well as the elementary composition of the different fractions of the average household waste (food waste, newspaper, corrugated board, mixed cardboard, polyethylene (PE), polypropylene (PP), polystyrene (PS), polyethylene terephthalate (PET) and polyvinyl chloride (PVC)). In Table 4.3 the average composition of the waste under study is presented and the elementary composition is shown in Table 4.4.

From here on the term average household waste will sometimes be shortened to waste, even though the study only covers a limited part of the total waste produced.

4.2 Average household waste composition

According to RVF (The Swedish Association of Waste Management) the total amount of so called household waste in 1998 was 3 810 000 tonnes (RVF 1999). This figure includes waste from household bins, bulky waste, garden waste and waste from shops and offices. In the following only the first part, waste from household bins, is considered.

To estimate the average household waste composition the result from a study by REFORSK is used (Olsson and Retzner 1998). The composition of collected household waste is in the study described for six municipalities in Sweden (Kalmar, Tidaholm, Kristinehamn, Eskilstuna, Skellefteå and Tomelilla). Waste from a one-family house amounted to, on average, 9.2 kg/week and for households in blocks of flats the average amount was 5.7 kg/week. These figures would according to Olsson and Retzner give an approximate total of 1.5 million tonnes/year in Sweden. The composition of the waste collected is shown in Table 4.1.

Table 4.1 Average composition of waste from household bins in a study from 1998 (Olsson and Retzner 1998).

Packaging		**Non-packaging**	
Category	Weight-%	Category	Weight-%
Newspaper	6.0	Food wastes	40.4
Corrugated board	0.5	Diapers	5.8
Soft plastics	5.4	Garden waste	8.6
Hard plastics	2.4	Other paper	6.6
Paper packaging	6.7	Other plastics	1.1
Glass packaging	2.4	Textiles	3.0
Metal packaging	2.0	Wood	1.3
		Others	6.2
		Other glass	0.2
		Other metals	0.7
		Electronics waste	0.4
		Hazardous waste	0.2

In the study by Olsson and Retzner (1998) waste collected directly from the households is compared to waste sorted and separately disposed of at packaging recycling stations (Table 4.2).

Table 4.2 This table presents the amount of waste packaging collected at recycling stations and the amount of packaging which is found in the mixed household waste. The figures are from (Naturvårdsverket 1997), except for the figure for collected glass packages which is from Svensk Glasåtervinning AB (Olsson and Retzner 1998).

Packaging material	Collected at recycling stations (ton)	Collected with household waste (ton)
Newspaper	385 000	90 036
Corrugated board	251 000	8 211
Paper packaging	74 800	99 980
Plastic packaging	14 337	122 560
Glass packaging	134 200	36 929
Metal packaging	37 941	30 370

The fractions covered in this study are the combustible and recyclable or compostable ones. The waste definitions chosen by Olsson and Retzner (1998) are converted into the ones used here and therefore paper packages are assumed to be mixed cardboard and other paper to be newspaper. Plastic packages and other plastics are divided between polymers according to the distribution of these in packaging (74% PE, 10% PP, 8% PS, 4% PET and 3% PVC) (Naturvårdsverket 1996, p 4). The average composition of the waste dealt with in this study is presented in Table 4.3 The total amounts of the fractions under study sums up to 1 203 797 ton dry weight/year.

Table 4.3 Average composition of the household waste studied.

Waste fraction	Share (%)	Amount dry weight (ton/year)
Food waste	14.8	177 682
Newspaper	41.8	503 229
Corrugated board	19.8	238 952
Mixed cardboard	11.5	138 755
PE	9.03	108 652
PP	1.21	14 603
PS	0.967	11 641
PET	0.484	5 821
PVC	0.371	4 462

4.2.1 Composition of waste fractions

The elementary composition of the constituents of the average waste are presented in Table 4.4 and in the text below. These data are used as input in the incineration and landfill models (see process descriptions in sections 5.5 and 5.6). Explanations of the abbreviations used for the composition are given in Table 4.5, as well as explanations for the different materials.

To describe the composition of the different waste materials a modified version from Sundqvist et al. (2000, Appendix 2) is used. The components for the description of the composition are described in Table 4.5.

Table 4.4 Composition of the fractions of the average household waste studied.

(kg/kg TS)	Food waste	Newspaper	Corrugated Cardboard	Mixed cardboard	PE	PP	PS	PET	PVC
HHV (MJ/kgTS)	18.9[13]	19.0[8]	19.0[8]	19.0[8]	46.0[11]	46.5[1]	40.6[1]	29.0[3]	21.0[1]
TS	0.3[8]	0.88[9]	0.88[10]	0.79[8]	0.95[8]	0.95[8]	0.95[8]	0.95[8]	0.95[8]
C-fossil		0,008[7]	-	0,17[8]	0,856[1]	0,855[1]	0,889[1]	0,64[2]	0,401[1]
C-tot bio	0,434[8]	0,44[7]	0,5[6]	0,4[8]	-	-	-	-	-
-lignin	0,029[8]	0,14[7]	0,08[6]	0,059[8]	-	-	-	-	-
-cellulose	0,107[8]	0,3[7]	0,42[6]	0,34[8]	-	-	-	-	-
-starch and sugar	0,097[8]	0,002[7]	-	0[8]	-	-	-	-	-
-fat	0,135[8]	-	-	0[8]	-	-	-	-	-
-protein	0,066[8]	-	-	0[8]	-	-	-	-	-
H	0,058[8]	0,05[7]	0,06[6]	0,069[8]	0,142[1]	0,143[1]	0,083[1]	0,021[2]	0,051[1]
O	0,287[8]	0,38[7]	0,44[6]	-	0,0030[1]	0,0019[1]	0,0016[1]	0,34[2]	0,0065[1]
VOC	2,00E-6[8]	-	-	0[8]	-	-	-	-	-
CHX	1,00E-8[8]	-	-	0[8]	-	-	-	-	-
PAH	5,00E-7[8]	-	-	0[8]	-	-	-	-	-
Phenols	2,75E-5[8]	-	-	0[8]	-	-	-	-	-
PCB	4,35E-8[8]	-	-	0[8]	-	-	-	-	-
Dioxin	9,00E-14[8]	-	-	0[8]	-	-	-	-	-
Cl	3,9E-3[8]	6E-6[7]	-	1,7E-3[8]	-	-	-	-	0,538[1]
N-tot	0,020[8]	-	-	2,6E-3[8]	-	-	-	-	-
P-tot	3,8E-3[8]	-	-	4,7E-4[8]	-	-	-	-	-
S-tot	2,4E-3[8]	-	-	1,2E-3[8]	-	-	-	-	-
Al		0,015[7]	-	-	-	-	-	-	-
K	9,3E-3[8]	-	-	1,2E-3[8]	-	-	-	-	-
Ca	0,028[8]	0,006[7]	-	1,4E-2[8]	-	-	-	-	0,04[4]
Pb	1,00E-5[8]	3,5E-6[5]	5,5E-6[6]	4E-6[5]	1,9E-4[5]	1,9E-4[5]	1,9E-4[5]	1,9E-4[5]	1,9E-4[5]
Cd	1,30E-7[8]	5E-8[5]	3,4E-7[6]	3,8E-8[5]	1,2E-7[5]	1,2E-7[5]	1,2E-7[5]	1,2E-7[5]	1,2E-7[5]
Hg	2,80E-8[8]	1,1E-8[5]	7E-8[6]	1,8E-8[5]	7,1E-8[5]	7,1E-8[5]	7,1E-8[5]	7,1E-8[5]	7,1E-8[5]
Cu	3,40E-5[8]	3,5E-5[5]	-	2,7E-5[5]	1,8E-4[5]	1,8E-4[5]	1,8E-4[5]	1,8E-4[5]	1,8E-4[5]
Cr	1,00E-5[8]	5,9E-6[5]	4E-6[6]	1,4E-5[5]	1,3E-5[5]	1,3E-5[5]	1,3E-5[5]	1,3E-5[5]	1,3E-5[5]
Ni	7,00E-6[8]	6,2E-6[5]	7E-6[6]	8,2E-6[5]	7,7E-6[5]	7,7E-6[5]	7,7E-6[5]	7,7E-6[5]	7,7E-6[5]
Zn	8,00E-5[8]	4,2E-5[5]	2E-5[6]	4E-5[5]	1,9E-4[5]	1,9E-4[5]	1,9E-4[5]	1,9E-4[5]	1,9E-4[5]
Clay		0,07[7]							
DEHP									0,05[4]
DOM									0,02[4]

- Indicates no data available

[1] (Zevenhoven et al. 1995, p 8 to 9).

[2] Own calculations from the chemical formula $(C_{10}O_4H_4)_n$ gives the C, O and H values.

[3] (RVF 1996, p 19-20 and appendix 2).

[4] Own calculations from Naturvårdsverket (1996) and Kemikalieinspektionen (1996). Based on assumptions presented in the section on PVC composition.

[5] from Berg et al. (1998).

[6] (Olsson 1999) personal communication.

[7] calculated from Sundqvist et al. (1997 p 96).

[8] (Sundqvist et al. 2000, Appendix 2).

[9] (Ekvall et al. 1993).

[10] (FEFCO et al. 1997p 17).

[11] (Björklund 1998, Appendix G, p G-2).

[12] (Björklund 1998) Appendix E, p E-8.

[13] calculated from (Björklund 1998) Appendix F, p F-1, using the HHV-values (MJ/kg C) for C-lignin: 40.89, C-cellulose: 37.51, C-starch and sugar: 39,57, C-fat: 51,25, C-protein: 45,07, VOC: 50,1 and CHX: 35.0.

Table 4.5 Explanation of the abbreviations used for the description of compositions.

Substance	Explanation
HHV	Higher heating value. Value for energy content including energy in steam produced in combustion.
TS	Total solids. Weight after evaporating moisture.
C-fossil	Carbon of fossil origin, e.g. carbon in plastics.
C-tot bio	Carbon of biological origin.
-lignin	Carbon in stable carbohydrates, e.g. lignin
-cellulose	Carbon in semi-stable carbohydrates, e.g. cellulose.
-starch and sugar	Carbon in degradable carbohydrates, e.g. starch and sugars
-fat	Carbon in fat
-protein	Carbon in proteins
H	Hydrogen (except hydrogen in water)
O	Oxygen (except oxygen in water)
VOC	Volatile organic compounds, including methane
CHX	Volatile halogenated hydrocarbons
PAH	Polyaromatic hydrocarbons
Phenols	
PCB	Polychlorinated biphenyls, existing in organic waste
Dioxin	TCDD equivalents, measured according to Eadon
Cl-tot	Total chlorine
N-tot	Total nitrogen
P-tot	Total phosphorous
S-tot	Total sulphur
Al	Aluminium
K	Potassium
Ca	Calcium
Pb	Lead
Cd	Cadmium
Hg	Mercury
Cu	Copper
Cr	Chromium
Ni	Nickel
Zn	Zinc
Clay	Chaolin, $Al_2(OH)_4Si_2O_5$, used in magazine paper
DEHP	Dietylhexylftalat, exemplifies the total of plasticisers in PVC
DOM	Dioktyltinmaliat, exemplifies the total of stabilisers in PVC

Food waste

For food waste the composition given in Sundqvist et al. (2000, Appendix 2) is used.

Newspaper

Newspaper makes out a rather large part of the total household waste, measured in weight. In this study a waste mix of 70% newspaper and 30% magazine paper is assumed. Data for the elementary composition of these two fractions are from Sundqvist et al. (1997, p 96).

Newspaper is made up to 99% of mechanical pulp, which in turn is made up of 73% cellulose ($C_6H_{10}O_5$) and 26% lignin ($C_{10}H_{11}O_3$). Magazine paper is composed of 29% bleached mechanical pulp and 38% mechanical pulp. The rest is mostly china clay (24%), lime (5%) and polystyrene-butadiene (3%). Only part of these three contents is used in the composition data. China clay, or chaolin, has the chemical formula $Al_2(OH)_4Si_2O_5$, and is contributing to the composition data as clay, but also as aluminium. Lime, ($CaCO_3$), is included as carbon and calcium. Polystyrene-butadiene $(C_{12}H_{14})_n$ contributes with fossil carbon to the newspaper composition data.

Cationic starch, $(C_6H_{10}O_6)_n$, is part of both newspaper and magazine paper and is reported as starch-carbon.

Some constituents presented in Sundqvist et al. (1997 p 96), polyacrylicamid, polyacrylicacid, CMC (carboxymethyl cellulose), PE (polyethylene), and PE-imin, are left out of the here defined composition of newspaper. The amounts are small and are considered to be of little importance here.

Data on heavy metals content are from Berg et al. (1998 p18). The data given there are averages for newspaper, journals and magazines and is assumed to be suitable as an approximation of the heavy metal content of the newspaper fraction studied here.

Corrugated cardboard

The amount of corrugated cardboard in the household waste considered in this study is comparatively small. Much of this waste fraction is formed in industry and business. The major part of the amount arising in households may be handled as bulky waste.

Corrugated board is composed of two different papers, an inner layer (fluting or wellenstoff) and the outer layers (kraft- or testliner). The average weight ratio between these two is 4:6 (Olsson 1999). Fluting and kraftliner are produced mainly from virgin wood and wellenstoff and testliner are their recycled counterparts.

Personal communication with Lars Olsson(1999) is the source of the figures for the composition of corrugated cardboard.

Mixed cardboard

Mixed cardboard in household waste is mainly packaging. The data on the composition of mixed cardboard are from Sundqvist et al. (2000, Appendix 2), except for the figures on heavy metals content, which are from Berg et al. (1998 p 18). Out of the cardboard weight, 10% is assumed to be plastics (Sundqvist et al. 2000, Appendix 2), the inner layer of e.g. milk packages, and this plastics is assumed to be polyethylene.

Plastics

The plastic fractions considered in this study are:
PE – polyethylene
PP – polypropylene
PS – polystyrene
PET – polyethylene terephtalate
PVC – polyvinyl chloride

PE constitutes the largest part of plastics in packaging, which is the approximation used here for household waste. About one forth of the total amount of plastics consumed in Sweden is used in packaging (Naturvårdsverket 1996 p 3). It is assumed that packaging is the major source of plastics ending up in household refuse bins. Data for HDPE (High-Density PE) from (Sundqvist et al. 2000) is used as an approximation for PE.

Data on the composition of different plastic materials are from Zevenhoven et al. (1995 p 8-9). For PET the C-H-O relation is calculated from the chemical formula.

In an evaluation of composting by Rondeco one of the fractions are mixed waste (Berg et al. 1998 p 14 and 18). This fraction contains 4.7 % soft plastics, 0.5% bottles and cans and 3% other plastics (percentage of wet weight). The heavy metal content in the three fractions are weighted with respective amount and added together. The resulting values are used as general amounts for all plastic fractions in our analyses.

The amounts and sorts of additives used in plastics vary a great deal and it is therefore difficult to define a general average composition of a polymer. For all the plastic fractions except PVC only heavy metals, as described above, represent the potential content of additive substances. For PVC we have tried to include some more. These approximations of additives, their composition and average use within PVC are based on data for the construction sector, but are here used for PVC in household waste (Naturvårdsverket 1996). Soft PVC (20%) (e.g. flooring materials) are assumed to contain 25 weight-% plasticisers (accounted for as DEHP, dietylhexylftalat), 1.5% stabilisers (accounted for as DOM, dioktyltinmaliat) and 25% calciumcarbonat ($CaCO_3$). Other PVC (80%) (pipes, windows and profiles) are assumed to contain 2% stabilisers (counted as dioktyltinmaliat, DOM) and 7% $CaCO_3$.

Average PVC would then contain 5% DEHP, 2% DOM, 10% $CaCO_3$. The $CaCO_3$ is accounted for as calcium and fossil carbon in the composition data.

The content of chemicals in the plastic fractions studied here may be under-estimations for some fractions, which should be kept in mind. Metal content may be exaggerated for some plastics, e.g. PE and PET, which usually contains few additives, and under-estimated for others.

5. Processes

5.1 Introduction

The waste may be managed in different ways. The options covered in this study are, as mentioned earlier:

- Recycling of material
- Anaerobic digestion, digestive residue used as fertiliser
    - with biogas used for heat and electricity generation
    - with biogas used for fuelling vehicles
- Composting, composting residue used as fertiliser
- Incineration, with heat recovery
- Landfilling, with landfill gas used for heat and electricity generation

The data and system boundaries used for inventorying these waste management processes, as well as three other main processes, electricity production, transports and heat production, are presented in this chapter. For some readers, it may be that this chapter will serve as a guide to return to for looking into details of a specific process and not for reading in detail.

The electricity used in the processes described in this chapter is, when possible, assumed to be produced from hard coal. This assumption is discussed in 3.2. The transport distances are presented in 3.4. In many of the processes in this study additives are used. When possible, these have been followed to the cradle using data available in different databases. The quality of these data is varying.

The process data records in Sima Pro 4.0 for the processes described in this chapter can be found in Appendix 5. Additives, transport vehicles and energy included in the processes presented here are also shortly described in Appendix 1 with the corresponding process data records in Appendix 5. Names written in italics are the names as written in Sima Pro and thus in the appendices.

5.2 Recycling

5.2.1 General description

Recycling of materials can be done in several ways. Some materials may also be recycled into energy. In this study we define recycling as materials recycling only, conversion into energy is handled under incineration.

To be able to recycle waste materials some kind of sorting has to be performed. This may either be done centrally, by collecting mixed waste and sorting it at a central unit or it may be done in the household. In this study we assume the latter option, since this is the common way of sorting and collecting waste packaging materials for recycling in Sweden.

Waste materials handled in this study that may be considered for recycling are the different plastics, newspaper, mixed cardboard and corrugated cardboard. When a material is recycled it will replace some other material. It is in this study generally assumed that the replaced material is of the same kind and would have been produced from virgin resources. In one scenario, however recycled plastics is assumed to replace impregnated wood. This is described in 5.2.9.

Most materials are here modelled so that one kg of waste material will not replace exactly one kg of virgin material. This is because of losses and sorting out during the processes, and in the case of paper and board products the fact that the quality will not be as good and therefore a larger amount of fibre will be necessary in the recycling case.

Below, the recycling and virgin production processes will be described for each material.

5.2.2 Newspaper

Recycling

Data for recycling and also for the virgin production of newspaper originates from a study made for REFORSK (Baumann et al. 1993). Data are mainly from three Swedish paper mills, Hallsta, Braviken and Hylte paper mills. Below, a short description of the data and assumptions made in this study are presented. For more details see Baumann et al. (1993). A simplified flow chart for the recycling of newspaper is shown in Figure 5.1.

In the production of newspaper from used paper 70% of the used paper is assumed to be newspaper, the other 30% a mix of journals, magazines, etc. In addition to the recycled fibre, 16% of the pulp is thermo mechanical pulp (TMP) from wood (the same pulp as is used in the virgin production described below).

Included in the inventory for newspaper recycling are data for transportation and reloading of waste paper, production and transportation of chemicals used in production of recycled pulp, production of recycled pulp, wood extraction, transportation of wood to mill, production of TMP, and production of paper.

In the recycled pulp production process some chemicals are added. The chemicals may vary between the mills but the ones modelled here are caustic soda, hydrogen peroxide, water glass, de-inking substance and lime. Data inventoried for the chemicals are aggregated and include energy from electricity and oil and emissions of total organic carbon (TOC).

We assume that reloading of waste paper at the reloading point is performed by a vehicle with resources use and emissions similar to a tractor (see data for *Tractor I* in Appendices 1 and 5).

Losses during reloading as reported by Baumann et al. (1993), (2%), are neglected. The recycled pulp production process has an exchange factor of 0.85. Most of the losses are string and ink, plus some fibre losses.

For the different energy uses we have made the following assumptions. The source of the electricity used in the pulp and paper production processes, for reloading of waste paper and the production of chemicals is coal power. Heat production in bark boilers is modelled as heat production from forest residues (described in section 5.9.2). Heat production in CFB boilers is modelled as heat from oil (described in section 5.9.4) when defined as fossil fuel by Baumann et al., and when it is defined as renewable fuel we have modelled it as heat from forest residues.

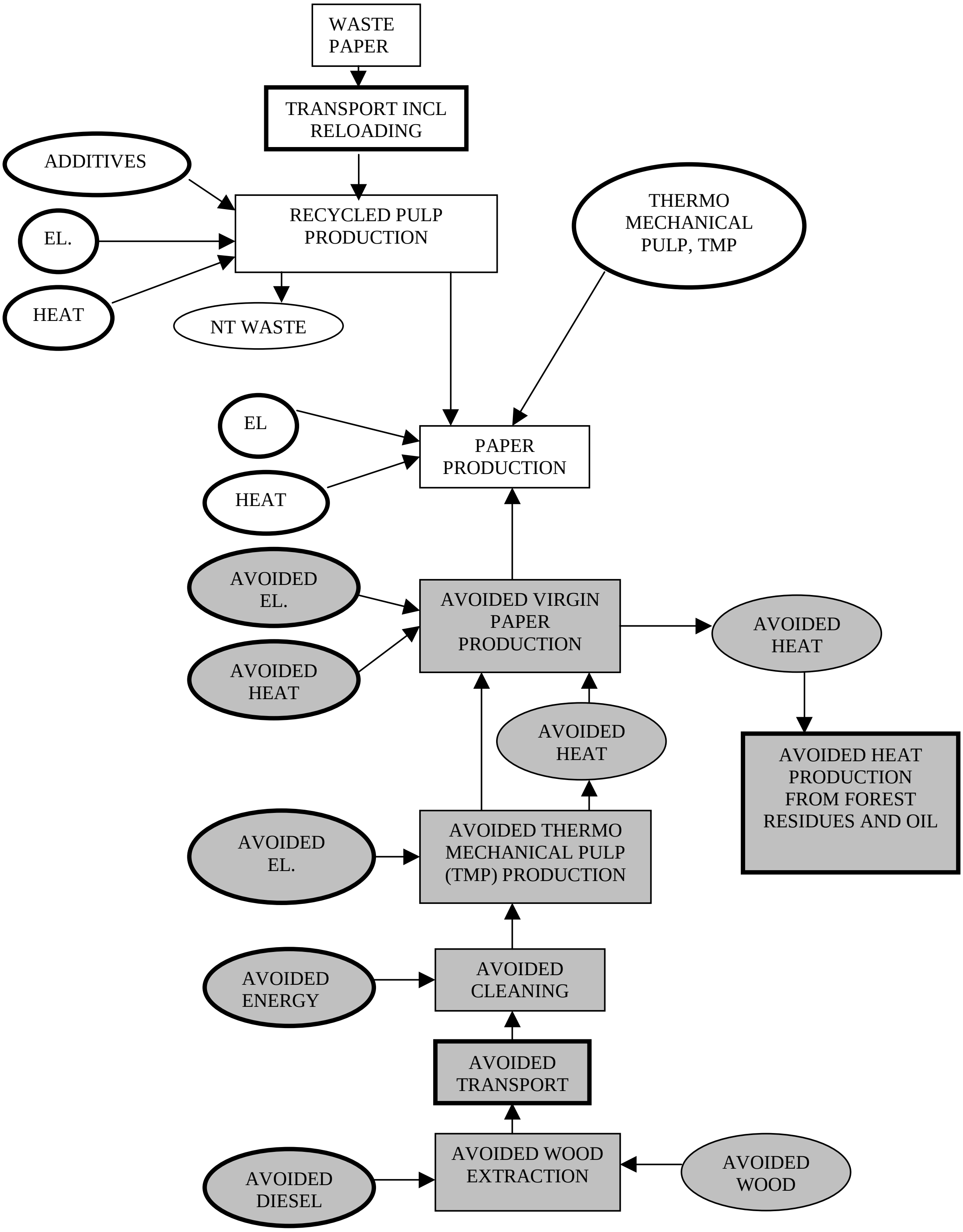

Figure 5.1 A simplified process flow chart for the newspaper recycling system. Boxes indicate processes and circles are flows. Thicker lines indicate that there are more processes and data connected to the box/circle within the study, than those shown in the flow chart. NT waste means non-treated waste. Grey areas show avoided processes and flows. Processes and flows that are not included in the study because of lack of data or because they were considered to be of minor importance are not included.

Waste from reloading of waste paper and waste from the production of recycled pulp are not followed to the grave. This waste is categorised as non-treated. It is inventoried as waste and will be categorised as such. The amounts are small and emissions from the incineration and /or landfill of this waste are assumed to be insignificant.

Virgin production

For virgin production of newspaper spruce is used as raw material. Here, wood extraction is assumed to be performed by a vehicle with resources use and emissions similar to a tractor (see *Tractor I* in Appendices 1 and 5). The transportation figure for wood from the forest to the mill, 250 km (both ways), is taken from Baumann et al. (1993). This transport is here assumed to be done with a diesel truck. Data for this vehicle (*diesel truck highway)* is described in section 5.8.1. Empty return is assumed. Energy use from taking care of incoming wood is included in the inventory data for pulp production.

According to Baumann et al. (1993) the thermo mechanical pulp process may be considered to be completely free of chemicals. The electricity used in the process will generate heat and the steam formed is subsequently used in the paper production process. Of the electricity input 63% will be recovered as steam. The amount of heat derived from steam is excluded from in- and output (it could otherwise be added under input and avoided energy production, and then equal zero). During the paper production process bark is used for heat production in a bark boiler. Heat and electricity is modelled as in the recycling process (see above).

5.2.3 Corrugated cardboard

Recycling

Data for recycling of corrugated cardboard is obtained from the European Database for Corrugated Board Life Cycle Studies (FEFCO et al. 1997). Data are weighted average 1996 data collected from Western European producers. FEFCO et al. supplies data both for recycled and virgin material.

The recycled versions of the two layers composing corrugated board are wellenstoff, the inner part, and testliner, the outer layers. A mix of recovered paper categories is used as raw material. The main input is category A, which is defined by CEPI (Confederation of European Paper Industries) as ordinary grades, and where “supermarket corrugated paper and board” and “old corrugated containers” are included (CEPI and BIR 1999). Here it is assumed that waste corrugated board is the sole input to the production of testliner and wellenstoff.

Energy used in the production of testliner and wellenstoff are from natural gas, heavy and light fuel oil, diesel oil, LPG (liquefied petroleum gas) and lignite. These are shortly presented in Appendices 1 and 5 as *natural gas B300, oil heavy B300, oil light B300, diesel B300, LPG I* and *crude lignite*. Electricity produced at the sites themselves is not reported. However, electricity sold to the public grid is recorded as avoided electricity production. The source of the electricity used and avoided is coal power.

Losses and residues are not followed to the grave. They are reported as solid emissions (ash, sludge, paper, rejects and other waste). These residues are reported to be landfilled or incinerated by FEFCO et al., but since there are no data on the composition of the residues no modelling of these processes are performed. This waste is characterised as non-treated.

Combining testliner and wellenstoff into corrugated board is left outside the system. The assumption is that this process is the same as for combining the virgin produced kraftliner and semichemical fluting described below into virgin corrugated board. To get more similar properties to virgin materials an extra 10% input of recycled paper is assumed to be needed (Olsson 1999) and this is included in the study

Additives are used in the production processes. For the following additives upstream emissions and inputs are in some way included, *phosphoric acid I, HCl (100%) B250, NaOH P (1998), urea and starch NL (potato) max*. A description of the inventory data for these substances is provided in Appendices 1 and 5. Other substances, *biocides, defoamers*, *lubricants*, *retention agents*, *colorants* and *sizing agents* (the last two only used for testliner) are not followed to the cradle.

Virgin production

Virgin production of the constituents of corrugated board is modelled based on data from the same source as the recycling process (FEFCO et al. 1997). Some recovered paper is used also in this production, though these inputs are comparatively small.

Energy used in the production of kraftliner and fluting are from natural gas, heavy and light fuel oil, diesel oil, coal (only fluting), peat, bark and wood chips. Data for the energy produced internally from residues and black liquor is not included in the inventory. The inventory data for the fuels previous to combustion are shortly described in Appendices 1 and 5 under *natural gas B300, oil heavy B300, oil light B300, diesel B300, coal B300* and *wood FAL*. Peat is not followed to the cradle. Electricity produced at the sites themselves is not reported. Avoided heat production is modelled differently in the different scenarios. Both electricity bought and avoided is modelled as being produced from coal. Avoided products from Kraftliner production also include tall oil and turpentine. No credit is given for these, since no data has been available.

Losses and residues are handled as described above for recycling.

Data were available for the fluting additives *quicklime (CaO in reference document), calcium hydroxide, phosphoric acid I, sulphuric acid B250,* HNO_3, *HCl (100%) B250,* $NaClO_3$, *NaOH P (1998)*, *sodium sulphate (*$NaSO_x$ *in reference document), pulp for cardboard B, ammonia P, sulphur B250* and *sulphur dioxide B250* (see Appendices 1 and 5). Additives not followed to the cradle in the fluting production process are *defoamer, lubricant, magnesium oxide,* Na_2CO_3 and *pitch despergents.*

For kraftliner inventory data are given for *aluminium sulphate, sulphuric acid B250, HCl (100%) B250,* Na_2SO_4, *NaOH P (1998), sulphur B250, starch NL (potato) max, limestone B250 (*$CaCO_3$ *in reference document),* and *quicklime (CaO in reference document*) (see Appendices 1 and 5). Additives not followed to the cradle are *defoamer, lubricant, pitch despergents, biocides, soda, retention agents* and *sizing agents*.

5.2.4 Mixed cardboard

Recycling

Data for recycling of mixed cardboard are from Sundqvist et al. (2000, Appendix 2). They have in turn used data from the Swedish facility Fiskeby Board (from 1997).

It is assumed that mixed cardboard waste is the only raw material, even though some paper and newspaper may in fact be included. To obtain similar properties as for virgin cardboard an extra 15% weight is assumed for the recycled board (Sundqvist et al. 2000, Appendix 2).

The 10% plastic content of the waste mixed cardboard is separated from the rest and incinerated. Transport to the incineration facility is excluded. The incineration process is here assumed to be the same as for incineration of PE (see section 5.5 and process data records in Appendix 5).

At Fiskeby Board energy from oil and electricity is used in the recycling process. The ratio between these two differs substantially from one year to the other. In the inventory an average of the amounts in 1996 and 1997 is used. Precombustion data for oil is included in the inventory using data for *oil heavy B300* (described in Appendices 1 and 5) and the electricity is from coal-fired plants.

Outgoing water from the process is purified before reaching the recipient. The sludge thus formed, 0.0315 kg/kg mixed cardboard, is landfilled according to the model for sludge described in section 5.6.

Virgin production

Inventory data for virgin production of chlorine free mixed cardboard is based on the database KCL Data Master (KCL 1997). Data are obtained from Sundqvist et al. (2000, Appendix 2). According to Sundqvist et al., data include input of nutrition to wood plantations and emissions from these to water, treatment of wood at the mill, production of pulp and paper, production of heat and treatment of outgoing water.

Energy for the production process is from oil and electricity. Precombustion data for oil is included in the inventory using data for *oil heavy B300* (described in Appendices 1 and 5) and the electricity is from coal power.

Transport of wood from the forest to the production facility is assumed, by Sundqvist et al., to be 150 km. Resource use and emissions from transports are aggregated with the other inventory data.

Chemicals are used in the production of cardboard. Data used for CaO, H_2O_2, H_2SO_4 and $NaOH$ are shortly described in Appendices 1 and 5. Other chemicals are not followed to cradle because of lack of available data. These are *artificial fertiliser, sawchain oil, hydraulic oil,* $MgSO_4$, *N-chemical,* O_2, O_3, and *EDTA*.

Some waste defined as industrial waste is formed during the production chain. This waste is not further followed, but inventoried as non-treated waste.

5.2.5 PE

Recycling

Data for the recycling of PE is from Sundqvist et al. (2000, Appendix 2). These data are based on data for the recycling facility in Arvika, Sweden. Recycling of HDPE (High Density Polyethene) and LDPE (Low Density Polyethene) are comparable and the model is assumed to be applicable for both.

The first step in the recycling process chain is the sorting of waste plastics in the households. The waste is then sorted a second time before reaching the recycling facility, where a final more careful sorting is performed. At this last stage approximately 40% of the plastics reaching the facility is rejected. This reject is modelled as mixed plastics and its composition is described in section 5.2.10, table 5.2. The reject is incinerated. Generated emissions and resources used for this incineration are included and documented in the process data record for PE-recycling (see Appendix 5). Reject formed at the earlier, and more coarse sorting and during the actual process of recycling is assumed to be insignificant, and is not included in the study.

No emissions to air from the processing are reported, since no measurements of air emissions are performed at the Arvika facility.

After sorting, the PE is washed using 20 litres of water per kg plastic. Emissions to water are formed during washing, figures for these are measurements from one single occasion, but they have, according to Sundqvist et al. (2000, Appendix 2), proven comparable to figures in the literature. Sludge is formed in the washing step (0.028 kg sludge/kg PE) and it is taken care of through landfilling (section 5.6).

The electricity used is generated in coal power plants.

Virgin production

Data for the virgin production of PE originate mainly from PWMI (European Centre for Plastics in the Environment) and BUWAL (Boustead 1993, BUWAL 1998). Figures are averages of several European producers. Data are obtained from Sundqvist et al. (2000, Appendix 2), and the data used are for HDPE.

The inventory includes data covering the chain from extraction of raw material until the produced granules have been transported to Sweden. Transport of the granules to Sweden are assumed, by Sundqvist et al. (2000, Appendix 2), to be 700 km by truck. The electricity used is a European mix (0.39 MJ hydropower, 1.29 MJ nuclear power, 2.19 MJ coal, 0.4 MJ oil and 1.52 MJ natural gas). Data for electricity and transport are aggregated with the other resource and emissions data.

The reported resource inputs to the processes leading to virgin PE are iron, limestone, water, bauxite, clay and NaCl. Crude oil and natural gas are used both as fuel and feedstock.

Waste formed is inventoried as slag/ash, chemical waste, industrial waste and mineral waste and not followed to the grave

5.2.6 PET

Recycling

Data for the recycling of PET is from a study made for the Danish EPA and data are mainly from the Netherlands and USA (Person et al. 1998). Inventory data from this study include baling of PET bottles and recycling of PET to PET-resin. Baling involves the use of steel strappings and electricity. In the actual recycling process the inputs inventoried are water, polymer filter screens and nitrogen. The production of polymer filter screens and nitrogen are not included. For a simplified flow chart for PET recycling, see Figure 5.2.

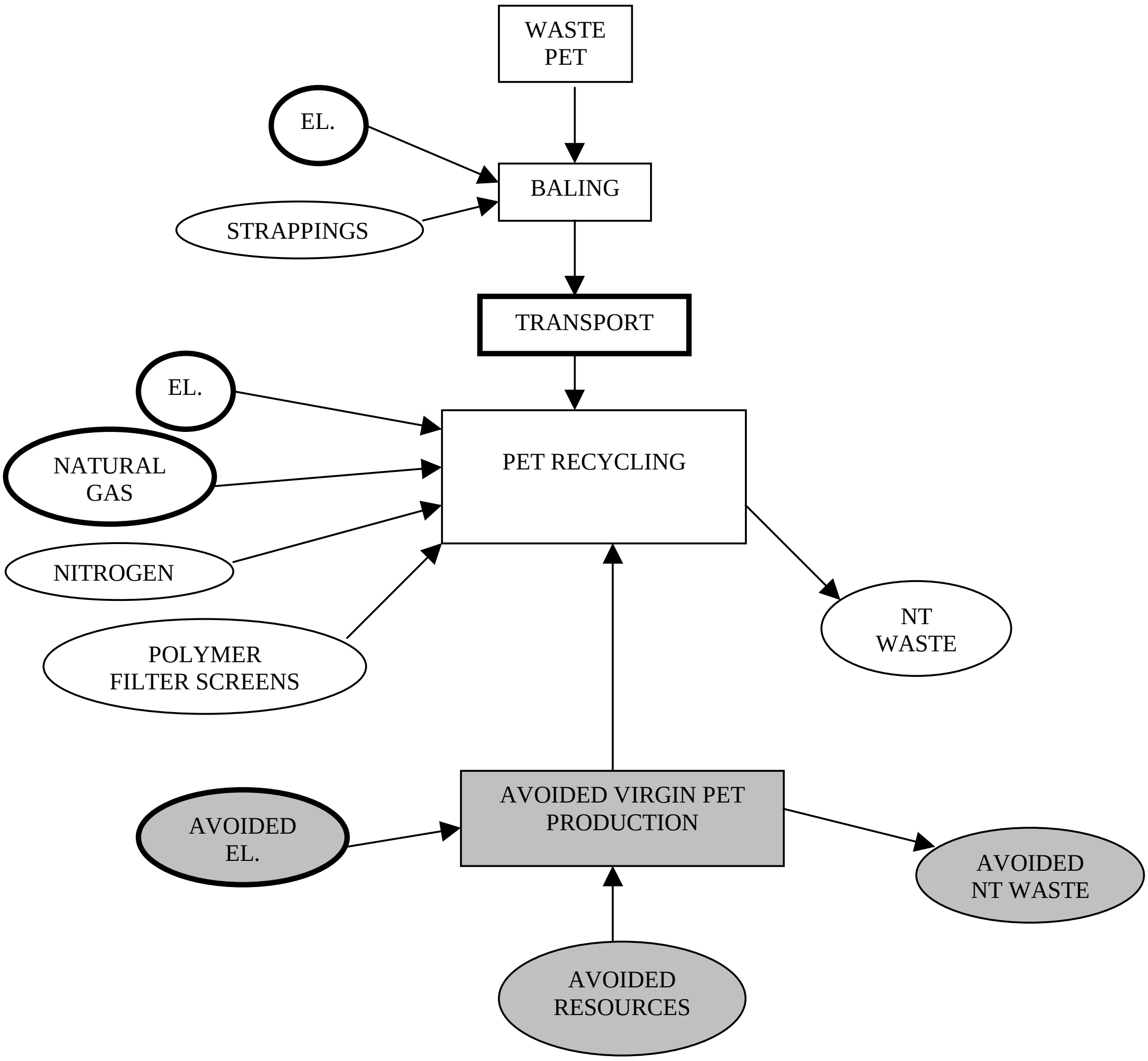

Figure 5.2 A simplified process flow chart for the PET recycling system. Boxes indicate processes and circles are flows. Thicker lines indicate that there are more processes and data connected to the box/circle included in this study, than those shown in the flow chart. NT waste means non-treated waste. Grey areas are avoided processes and flows. Processes and flows that are not included in the study because of lack of data or because they were considered to be of minor importance are not included.

Losses of polymer, 1.5%, and paper labels 2.3%, are not followed further. Incineration of these fractions is assumed to give negligible impacts. Waste derived from the filter screens and the output of glue is also not followed to the grave. These wastes are characterised as non-treated.

The electricity used is produced from coal. Heat from natural gas, described in section 5.9 is used for energy (as presented in Person et al.).

Person et al. (1998) state that the data are valid for production of PET-resin from 75% virgin PET and 25% of clean PET-flakes from recycled PET bottles, but they assume it to be a good approximation for the 100% recycling studied. Further, it is stated, that the recycling process involves PET-resin production from PET bottle flakes. The production of flakes is not included.

Virgin production

Virgin production of PET is based on ethylene and para-xylene. Data includes all process steps from extraction of feedstock resources (crude oil and natural gas) to solid state polymerisation (Person et al. 1998).

The data used are from the same report as the recycling data, but originate mainly from APME (Association of Plastics Manufacturers in Europe)(Boustead 1995). In these reports data are aggregated, making it difficult to separate emissions and resource uses between e.g. transports and process energy use. Person et al. (1998) have replaced electricity from hydro and nuclear power in the original data with electricity from coal condensing plants (using efficiencies 0.80 and 0.35, respectively).

The resources used in the process are bauxite, NaCl, clay, ferromanganese, iron ore, limestone, manganese, metallurgical coal, sand, water and phosphate rock. Crude oil, natural gas and coal are used both as fuels and feedstock resources.

Non-treated wastes are specified as mineral, ashes, mixed industrial, regulated chemicals and inert chemicals. These fractions are not followed to the grave.

5.2.7 PVC, PS and PP

Recycling

Data for recycling of PVC, PP and PS have been recorded by PRé Consultants. The original reference is (Sas et al. 1994). The process for which data is given is mechanical recycling and the materials thus recycled are PET and HDPE. PRé have assumed these figures also for PVC, PP and PS. This is an approximation including uncertainties. One of the main objections may be that it is harder to separate clean fractions of PVC, PP and PS than PET and HDPE. Here, the data are used as approximations for recycling of these materials.

For this study some modifications of the recorded data are made. The electricity sources as well as the transport distances are changed in accordance with the scenarios and assumptions used here. 40% of the incoming plastics is assumed to be rejected and incinerated with energy recovery. The figure 40% is assumed as it is the share that is rejected in PE recycling (Sundqvist et al. 2000, Appendix 2).

Virgin production

Data for virgin production of PVC, PS and PP are obtained from the SimaPro database and originate from PWMI (Boustead 1997a, b).

Figures for *PVC* production are averages from three polymerisation processes. It is stated that PVC usually contains lead or zinc as thermo stabilisers, but they are not included in the inventory. Resources inventoried are iron ore, limestone, water, bauxite, rock salt and sand. Natural gas, oil and coal are used as feedstock.

Virgin production of *PS* includes the use of iron ore, limestone, water bauxite, rock salt and clay minerals. The inventory of resources used in the chain of activities leading to the virgin production of *PP* include bauxite SO_2, sulphur, rock salt, gypsum, sand, iron ore, limestone and water.

The electricity data used is a mix and the constitution of this mix is depending on where the production facilities that the data is collected from are located. Fuels for electricity, process energy and transportation are aggregated. Fuels recorded in the *PVC* inventory consist of 18% energy from coal, 15% from oil, 41% from natural gas, 2% from hydro power and 23% from uranium. For *PS* the fuels are divided as 2% energy from coal, 62% from oil, 34% from natural gas, 0.1% from hydropower, 2% from uranium and 0.2% from lignite. In the *PP* inventory the shares are 5% energy from coal, 52% from oil, 37% from natural gas, 3% from both hydropower and uranium.

Waste produced under the virgin production chain not followed to the grave is classified as non-treated waste. It is inventoried as solid emissions and consists of slag/ash, metal scrap, unspecified and mineral, industrial, chemical (inert), chemical (regulated), construction, packaging and incinerator waste.

5.2.8 Saved forest from paper recycling

In one scenario the biomass saved from virgin production of paper, when recycling the paper fractions of the waste, are used for heat production as described in section 3.3. For calculating the heat produced from the saved biomass first the amount of biomass saved is calculated for the waste fractions, newspaper, corrugated board and mixed cardboard, respectively. The amounts are presented in Table 5.1. The amount of heat produced from 1 kg of biomass with 50% moisture saved is 8.9 MJ. The heating value is 8.4 MJ/kg and the degree of efficiency 1.06 as described in section 5.9 (Uppenberg et al. 1999). Only approximately half of the biomass avoided from virgin production of corrugated board is used for heat production, due to a mistake. However, this will not affect the overall conclusions of the study.

Table 5.1 The amount of biomass saved from virgin production when recycling waste paper fractions and the heat produced there from.

Waste fraction recycled	Saved biomass (kg/kg waste)	Heat produced from saved biomass (MJ heat/kg waste)
Newspaper	1.7 wet weight	14.3
Corrugated board	0.98 dry weight	8.7
Mixed cardboard	1.4 wet weight	12.6

The heat produced from the saved biomass will replace heat from natural gas in this scenario – the saved forest used as biofuel scenario.

5.2.9 Plastic palisade

Waste materials may be recycled in different ways and the resulting material may be used for different products. In one scenario plastic waste fractions are assumed to be recycled mixed together. The resulting recycled plastics material is used for palisades, replacing palisades made out of impregnated wood. Data for recycling of mixed plastics and production of palisades is obtained from Heyde and Kremer (1999) and is shortly presented here.

Recycling of mixed plastic waste into palisades

To produce 100 pieces of palisades 1.41 tonnes of sorted mixed plastics waste is recycled. The treatment chosen to exemplify this mechanical recycling of mixed plastics is agglomeration. This treatment needs 558 kWh electricity to produce 100 pieces of palisade. Residues from the recycling are assumed to be similar to the sludge produced in recycling of

PE as described in section 5.2. This sludge is landfilled and emissions from this waste handling are included in the inventory.

Following the agglomeration process is the extrusion. Electricity demand for this step is 287 kWh. 1% colour batch is added, this additive is not followed to the cradle or grave. Water leaving the production system at the two process steps are excluded form the inventory. During the extrusion cutting residue is formed. This residue is assumed to be incinerated and the ashes landfilled.

Production of the palisades from recycled plastics and transportation of the palisades to the place of use is not included in the data, it is assumed to be approximately the same for wood and recycled plastics.

100 pieces of palisade is produced, weighing 1.1 ton. After use the palisades are assumed to be incinerated with heat recovery. For this process and for the incineration of cutting residue data for PE incineration is used as an approximation.

Plastic palisades may have a longer service life than the same product made out of impregnated wood. According to Heyde and Kremer (1999, p 62) there are currently no data available on mixed plastics palisades lifetimes. In their study two cases are assumed, on the one hand equal lifetimes for plastic and wooden palisades and on the other plastics palisade lifetime exceeding wooden palisade lifetime four times.

Here, it is assumed that one plastic palisade replaces one palisade made of wood.

Virgin production of palisade from wood

Data for the production of palisades from wood include fuels for the wood production. 15% of the wood affected in the process is left in the forest, this is unavoidable waste. The wood is then transported to the sawmill. Fuel for the transport is aggregated with other fuel used at the sawmill. Electricity is also used at the sawmill. From the sawmill three products are obtained, trunk wood for the production of palisades, piecewood and sawdust. Here it is assumed that both piecewood and sawdust are used for heat production. This is described in section 5.6 and Appendix 5 *Wood incineration*. The composition of piecewood and saw dust is presented in section 5.2.10, Table 5.2, as wood. The trunk wood is boiler pressure impregnated using Cu-HDO preparation Wolmanit CX-SD and electricity. To estimate the copper content of the preservative data for Wolmanit CX-SC is used as an approximation. The content of copper is 72 g/kg preservative (Erlandsson 2000). During use 29% of the copper will be emitted to the surroundings (Erlandsson 2000).

The service life of the impregnated wooden palisades is estimated to around 25 years (Heyde and Kremer 1999, Erlandsson 2000). Thereafter the palisades are assumed to be incinerated with heat recovery. This process is described in the section 5.6 and Appendix 5 *Impregnated wood incineration.* The composition of impregnated wood is presented in section 5.2.10, table 5.2. 100 pieces of palisades equals 819.5 kg wood to be burned, this wood is contaminated with the copper not emitted during service life. Landfilling of the ashes produced is assumed. In the modelling of this all biological carbon remaining in the ashes is assumed to be medium degradable.

5.2.10 Composition of mixed plastics, wood and impregnated wood

In some recycling and virgin production processes residues are produced. The compositions of three of them are not presented earlier and are thus presented here in Table 5.2. Mixed plastics is used in the PE-recycling process as described in section 5.2.5. Wood and impregnated wood are used in the process production of palisades from wood as described in section 5.2.9.

Table 5.2 Composition of the materials mixed plastics, wood and impregnated wood.

(kg/kg TS	Mixed Plastics	Wood	Impregnated Wood
HHV (MJ/kgTS)	35.4[3]	19[5]	19[5]
TS	0,95[2]	-	-
C-fossil	0,73[2]	-	-
C-tot bio	-	0.30375[1]	0.30375[1]
-lignin	-	-	-
-cellulose	-	-	-
-starch and sugar	-	-	-
-fat	-	-	-
-protein	-	-	-
H	0,12[2]	-	-
O	0,048[2]	-	-
VOC	-	-	-
CHX	-	-	-
PAH	-	-	-
Phenols	-	-	-
PCB	-	-	-
Dioxin	-	-	-
Cl	0,038[2]	1.50E-03[1]	1.50E-03[1]
N-tot	3,00E-3[2]	1.50E-03[1]	1.50E-03[1]
P-tot	8,20E-4[2]	-	-
S-tot	1,50E-3[2]	7.50E-04[1]	7.50E-04[1]
Al	-	-	-
K	1,50E-3[2]	-	-
Ca	4,90E-3[2]	-	-
Pb	2,10E-4[2]	-	-
Cd	3,70E-7[2]	-	-
Hg	6,00E-8[2]	7.50E-08[1]	7.50E-08[1]
Cu	1,50E-4[2]	-	3.32E-04[4]
Cr	1,60E-5[2]	-	-
Ni	7,60E-6[2]	-	-
Zn	3,30E-4[2]	-	-
Clay	-	-	-
DEHP	-	-	-
DOM	-	-	-

- indicates no data available

[1] (Sundqvist et al. 1997).

[2] (Sundqvist et al. 2000, Appendix 2).

[3] (Björklund 1998, Appendix E, p E-8).

[4] (Erlandsson 2000)

[5] (Energiförsörjning 1994)

5.3 Anaerobic digestion

5.3.1 General description

The anaerobic digestion process in this study is based on inventory data from Nilsson (1997). The inventory data was collected at the digestion plant in Kristianstad, Sweden. The plant works according to a one-stage anaerobic digestion process, under wet and mesophilic (+30-40°C) conditions. The plant receives organic waste mainly from households, food industry, restaurants and agriculture. To calculate the impact of digesting organic waste originating from households, allocation is done on weight basis as described in Nilsson (1997).

The original inventory data for anaerobic digestion is supplemented with data on metals according to the food waste composition described in chapter 4. The metal content for food waste presented in Table 4.4 is used. The metals are left in the digestion residue since it is a closed process.

The waste handling, excluding transports, is described for the dry weight of the food waste. The dry weight of the food waste is 30% of the wet weight as described in Table 4.4. A weight loss of 40% of the total solids (TS) in the food waste is assumed due to degradation to CO_2 and CH_4 during the digestion (Nilsson 1997). Transports are described section 3.4.

A simplified process flow chart for anaerobic digestion is shown in Figure 5.3. A more thorough description of the digestion process, describing all assumptions, calculations and data is presented in Nilsson (1997)

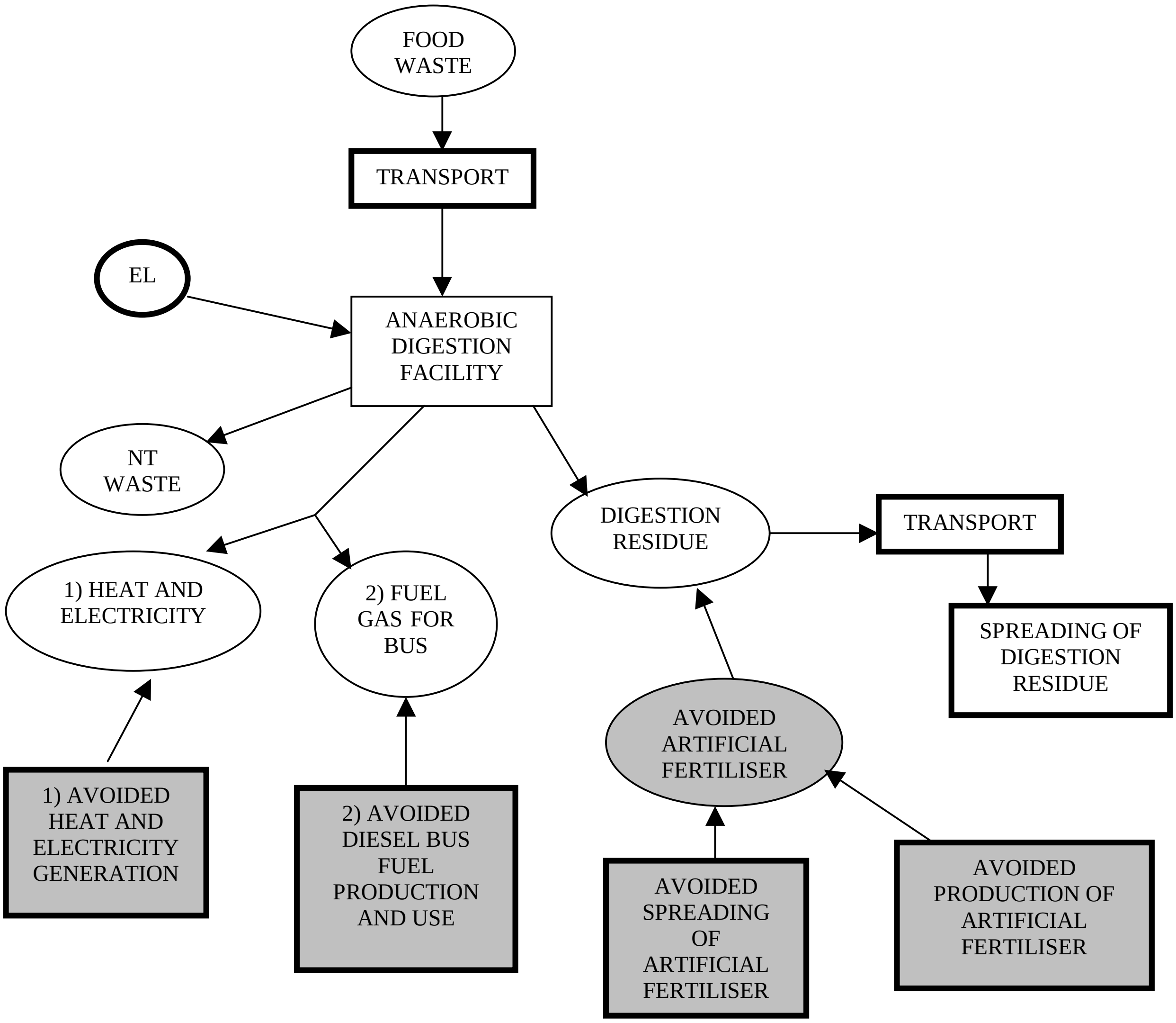

Figure 5.3 A simplified process flow chart for the anaerobic digestion system. Boxes indicate processes and circles are flows. Thicker lines indicate that there are more processes and data connected to the box/circle included in this study, than those shown in the flow chart. NT waste means non-treated waste. Grey areas are avoided processes and flows. The two different digestion options are both represented in the picture, 1) heat and electricity generation and 2) fuel generation. Processes and flows that are not included in the study because of lack of data or because they were considered to be of minor importance are not included.

Energy consumption

Electricity consumed in the process is 31 MJ/ton organic household waste. This electricity is coal based, according to the main assumptions of this study. The heat consumption of the plant is 495 MJ/ton organic household waste, using the produced methane gas as heat production source.

Nutrients content in digestion residue

The nutrient content in the digestion residue is defined by the parameters nitrogen (N) and phosphorous (P), 7.6 kg and 1.1 kg/ton respectively.

5.3.2 Transport and spreading of residues from anaerobic digestion and composting

We have in this study assumed that the residues from composting and digestion can be used as fertilisers which is not certain due to the risk of pollutants in the residues.

There are limits for how much nutrients that should be spread on to farmland. In Sonesson (1997) p 24-25 values for maximum doses per year for P and N are presented, for nitrogen 90 kg/ha and year and for phosphorous 15 kg/ha and year. The ratio between these two values determines which one is the dimensioning factor. Residues with lower N/P-ratios are P-limited and vice versa. The required acreage is calculated from the limiting nutrient content of the residues and the maximum dose, e.g. N/Nmax and P/Pmax(Sonesson 1997).

For the organic waste treated with anaerobic digestion N is dimensioning and the required acreage would be

Ra = 7.6/90 = 0.084 ha/ ton residue

For the organic waste composted in our study P is dimensioning and this would give a required acreage of

Ra = 2.0/15 = 0.13 ha/ ton residue

The distance that is travelled from the digestion or composting facility to reach the fields is assumed to be 5, 10 or 20 km depending on transport scenario (base, medium or long transport distances as described in section 3.4).

The energy required for spreading is approximately 20 MJ diesel/ton digestion residue and 15 MJ/ton compost (Dalemo JTI according to Nilsson 1997, p 53). The required area per ton residue and year are 0.084 and 0.13 ha respectively, which gives an energy use per ha of 238 MJ/ha and 115 MJ/ha.

The amount of residues produced from 1 ton of food waste is 858 kg for anaerobic digestion (14.2% weight loss, wet weight) and 500 kg for composting (50% weight loss, wet weight) (Nilsson 1997). The actual spreading will lead to consumption of 17 MJ diesel for digestion residue and 7.5 MJ diesel for compost.

There are large uncertainties in the data for spreading of residues from anaerobic digestion and composting. In some parts of the country where animal husbandry is more common the demand for other kinds of fertiliser may for example be low.

5.3.3 Avoided production of fertilisers, energy and fuel

Nitrogen and phosphorus-fertilisers

The concentration of nitrogen and phosphorus in the digestion residue from the anaerobic digestion process is used to calculate the avoided amount of artificial N and P-fertilisers. Inventory data for production of these fertilisers are based on Weidema et al. (1995).

The N-fertiliser is ammonium nitrate. The requirement of natural gas for the production of the nitrogen fertiliser is 19 MJ/ kg N.

The P-fertiliser is produced from raw phosphate adding sulphuric acid, which react further to form super phosphate. Process data for sulphuric acid is shortly described in Appendix 1. The transport of raw phosphate is not included in the inventory. Energy requirement for the production of the phosphorus fertiliser is 26.3 MJ oil/ kg P. Raw phosphate contains on average 15% P. The contamination of heavy metals in raw phosphate are generally not exceeding the levels found in average soils, except for arsenic (As), cadmium (Cd) and zinc (Zn) according to Weidema et al. (1995).

Weidema et al. have described raw phosphate contents of arsenic, cadmium and zinc. The content of arsenic in raw phosphate ranges from 7 – 2000 mg/kg P depending on its origin. The dominant raw phosphate sources have less than 100 mg As/kg P. We have assumed the concentration 100 mg As/kg P and complemented this to the original data. The content of cadmium in raw phosphate ranges from 0.9 – 350 mg/kg P depending on the origin. The Swedish legal limits for cadmium in P-fertilisers is set to 100 mg/ kg P. This concentration is assumed for cadmium when complementing the original data. The content of zinc in raw phosphate ranges from 20 – 5300 mg/kg P, with an average of 660 mg/kg P. This average value is assumed for zinc and added to the original data (Weidema et al. 1995).

Approximately 10 kg gypsum is produced as waste per kg P in the manufacturing of the fertiliser. The gypsum is regarded as non-treated waste, which is assumed to be landfilled. This gypsum contains 5-35% of the heavy metals (As, Cd and Zn) present in raw phosphate. We have assumed that the gypsum contains 35% of the metal contents in the raw phosphate given above. These heavy metals are inventoried as emissions to soil.

Spreading of artificial fertiliser requires 28.8 MJ/ha (Johansson 1998). The avoided energy use from spreading of artificial fertiliser is 2.4 MJ in the digestion and 3.7 MJ in the composting case.

Energy and fuel

The energy content of the methane gas collected from the anaerobic digestion is 3743 MJ/ton food waste, and of that 495 MJ is used internally at the plant. The remaining available methane gas is modelled to be utilised in two different ways, either for heat and electricity production or as bus fuel.

Production of heat and electricity is modelled according to Dalemo (1997). For production of energy, 60% becomes heat, 30% electricity and 10% is lost. Avoided heat and electricity production is described in the sections 5.9 and 5.7. Which heat producing fuel that is avoided depends on the scenario, described in section 3.3. The avoided electricity is produced from coal.

The data used for diesel fuel and its use in buses are based on the assumptions that a bus consumes 12.1 MJ/km. Data cover the precombustion of diesel and the use of it in a bus. Data are obtained from Sundqvist et al. (2000, Appendix 2) and are originally from Uppenberg et al. (1999) and Egebäck (1997). The energy used in the precombustion data is a mix consisting of 3% hydro power, 0.2 % biofuel, 3% nuclear power, 20% natural gas, 74% oil and 0.2% coal.

5.4 Composting

5.4.1 General description

The composting process in this study is based on inventory data from Nilsson (1997). The inventory data was collected at the composting plant at Marieholm in Gothenburg, Sweden in 1997. The plant receives organic waste of different origins. Except for source separated organic household waste the plant also treats garden waste, restaurant waste and manure. To calculate the impact of composting organic waste originating from households, allocation is done on weight basis as described in Nilsson (1997).

The original inventory data for composting is supplemented with metals according to the food waste composition described in chapter 4. The metal content for food waste presented in Table 4.4 is used and the fractions of these that are left in the residue are taken from Nilsson (1997). Furthermore, the collected leakage water from the compost process is treated at a municipal sewage treatment plant as described in section 5.6.2. The waste handling, transports excluded, is here described for the dry weight of the food waste. Transports are described section 3.4.

A simplified process flow chart of the composting system is given in Figure 5.4.

5.4.2 The composting process

The data are for an open string compost. This process can be divided into three stages, mechanical pre-treatment, composting and manufacturing of soil product. In the first stage the organic waste is disintegrated and mixed in a fodder mixer. Transport to and from the fodder mixer is taken care of by a wheel loader. Data used to describe the impacts of the wheel loader life cycle are approximated by using the data for a tractor (*Tractor I*).

In the second stage the waste is spread in strings to undergo composting for 10 weeks. Aeration of the strings is conducted by a pipeline system connected to a fan. By creating a negative pressure in the compost matter, a reduction of air emissions is received. The air is passed through a biological filter and then emitted. The filter consists of bark, which is returned to the compost when consumed. This system is complemented with a water drainage system collecting the drainage water, which is subsequently purified at a municipal waste water treatment plant as mentioned above. After 10 weeks the strings are moved with a wheel loader and the compost material is put to a final maturing for 12 to 24 weeks. The aeration and water drainage procedure is also included in this stage.

In the third stage, the compost material is mixed with a stabilising material like sand or peat in different proportions, depending on application, this is not included in the inventory data. It is followed by straining to receive the sizes 15 and 30 mm of the particles in the final compost residue.

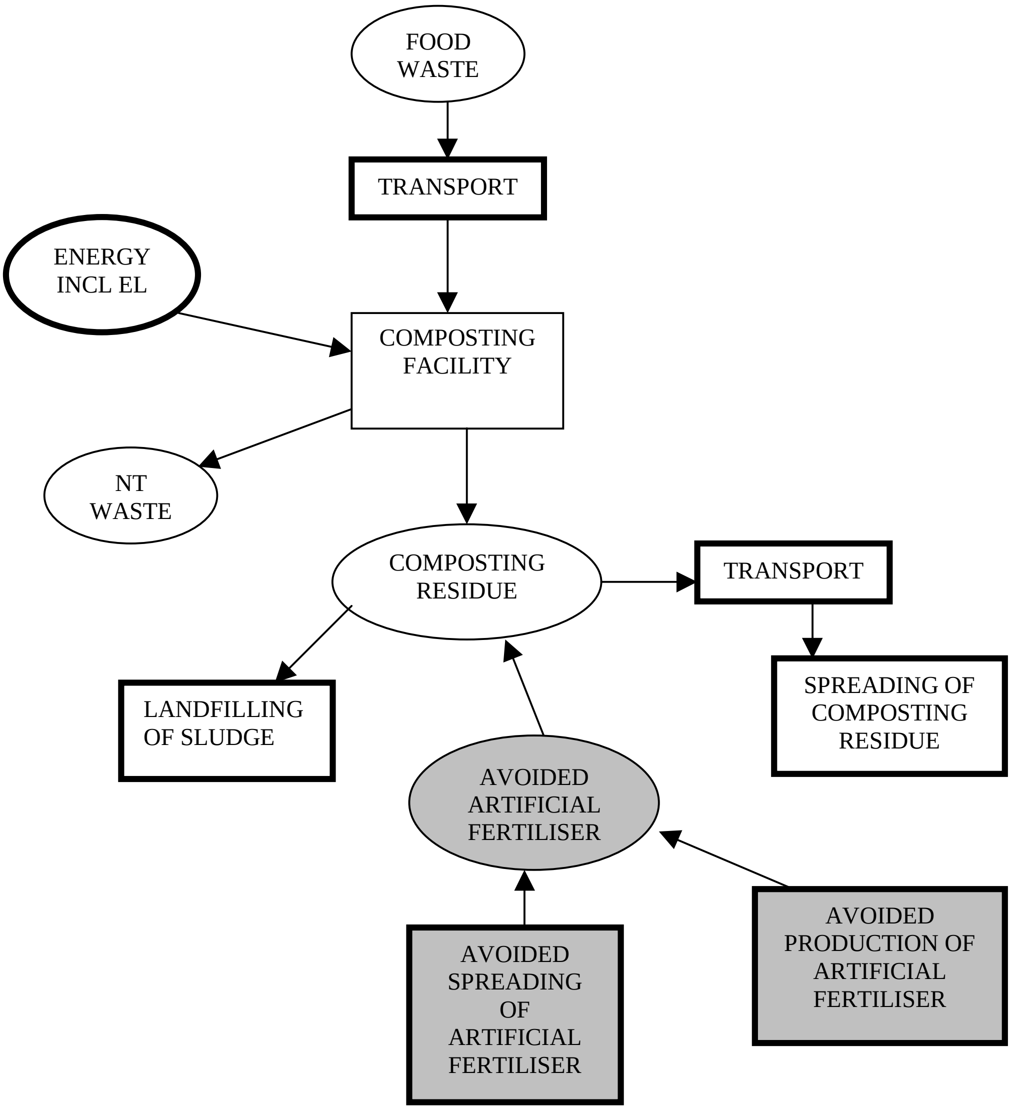

Figure 5.4 A simplified process flow chart for the composting system. Boxes indicate processes and circles are flows. Thicker lines indicate that there are more processes and data connected to the box/circle included in the study, than those shown in the flow chart. NT waste means non-treated waste. Grey areas are avoided processes and flows. Processes and flows that are not included in the study because of lack of data or because they were considered to be of minor importance are not included.

Energy consumption

Electricity consumed in the process is 54.4 MJ/ton food waste, which is here assumed to be produced from coal. The consumption of diesel in the wheel loader, different types of mills and a strainer is 555.5 MJ/ton food waste.

Air and water emissions

The nitrogen leakage to air is estimated to 7.5% of the nitrogen content in the compost. Of this leakage 89% is NH_3, 9% N_2O and 2% N_2. 60 % is assumed to be removed in the biological air filter. Amounts emitted are 0.28 kg NH_3 and 0.028 kg N_2O/ton food waste.

In the original data (Nilsson 1997), emissions to water are presented without any purification being made. Here, these emissions are modelled as treated in a municipal sewage treatment plant (see section 5.6.2).

Content of nutrients in the compost residue

The nutrient content in the compost residue is defined by the parameters nitrogen and phosphorous, 8.3 kg and 2.0 kg/ton food waste respectively.

5.4.3 Transport and spreading of residues from composting

Transport and spreading of residues from composting is described in section 5.3.2.

5.4.4 Avoided production of nitrogen- and phosphorus fertilisers

Avoided production of nitrogen- and phosphorus fertilisers is described in section 5.3.3.

5.5 Incineration

5.5.1 General description

Incineration is an expanding treatment option in Sweden. In 1997 there were 21 energy producing waste incineration plants for municipal solid waste and together these plants have 39 boilers in operation (RVF 1997). In 1995 the amount of waste incinerated was 1.8 Mton and the energy production was 5 TWh. The amount of waste incinerated has more than doubled since 1980 and the energy production has increased almost fourfold during the same period. The efficiency of the energy production has increased as well as the purification of the generated emissions (RVF 1997).

The incineration process in this study is based on an ORWARE (ORganic WAste REsearch model) sub-model for incineration (Björklund 1998). The inventory data for this sub-model was collected at the Uppsala incineration plant in 1993, and the model is specific for the plant in Uppsala. Incineration plants are normally individually constructed and may vary. Notable for the Uppsala incineration plant is the flue gas condensation, which is rather common in Sweden, but rarely used elsewhere (Björklund 1998). It enhances the efficiency of energy recovery, but generates an additional flow of waste water. According to Björklund (1998) modern waste incineration plants may differ in technical solutions, but it may be assumed that emissions are kept within the limits of legal restrictions, regardless of the composition of the incinerated waste. This suggests that, despite a site-specific approach, the model is rather general regarding emissions to air and water, for plants working under the same legal restrictions. Residual products, consumption of additives and energy recovery are more site-specific. A discussion concerning the potential effect on the results due to different degrees of efficiency at incineration plants can be found in section 7.12.1.

5.5.2 The incineration model

The elementary composition of the waste fractions studied, presented in chapter 4, is used as input in the incineration model. The model is divided into two parts; the *kiln* which generates outputs of bottom ash and raw gas, and the *air emission control system*, generating outputs of fly ash, condensed water and cleaned gas. Generation of heat and consumption of energy and additives are calculated within the kiln sub-model. The consumption of energy and additives within the incineration plant is calculated as depending only on the incoming amount of waste, except for urea which depends on the total nitrogen content in a waste material.

The heat released in the kiln is calculated either using higher heating values (HHV) of the carbon compounds in the incinerated waste material, or one HHV-value for the material in its entirety. For food waste the content of different carbon compounds is used to calculate the HHV-value as described in section 4.2.1, table 4.4. For the other waste materials included in this study the other procedure have been used. The HHV-values for the studied waste materials are presented in chapter 4. The heat efficiency of the incineration process is set to 0.90 and this is the upper efficiency, which includes flue gas condensation.

In the kiln, the waste is transformed into bottom ash and raw gas. Metals will largely end up in the bottom ash except for mercury and cadmium, which mostly go to the raw gas. The main parts of sulphur, phosphorous, nitrogen and chlorine end up in the raw gas. All carbohydrates, fats and proteins in the waste are assumed to be completely combusted, forming biological CO_2. Complete combustion is also assumed for phenols, PCB, VOC and CHX. Dioxins in waste will be combusted but new ones will be formed during the combustion.

The air emission control system consists of SNCR (Selective Non-Catalytic Reduction) with urea, acid removal by lime addition in the kiln, electrostatic precipitators, wet scrubbers, flue gas condensation and fabric filter. The air emission control mainly focuses on reducing acid gases, heavy metals, dust and organic pollutants. In the model, 99% or more of the dry matter and heavy metals in the raw gas will end up in the fly ash. The remaining part is about equally partitioned between clean gas and condensed water. From the raw gas, 30% of the dioxins are removed, SO_x is reduced by 95% and HCl by 99%, leaving the so called clean gas for emission to air. NO_x-emissions are calculated as a function of the energy content in the incinerated waste. Food waste contains nitrogen according to section 4.2.1, table 4.4., urea should therefore be consumed. The consumption of urea (8.20E-3 kg /kg foodwaste) has not been documented in the process data record for incineration of foodwaste in Appendix 5 and is therefor not included in the calculations.

The condensed water is flocculated, filtered and emitted to a recipient. Nearly 70% of the ammonia is removed from the condensed water. The condense water sludge is mixed with the fly ash and TMT 15 (Trimercapto-s-triazine-tri-sodium-salt) which reduces the leachability of the metals. The fly ash, which in the text here after also includes the sludge is then transported to a landfill.

Landfilling of the fly ash and the bottom ash is modelled according to Björklund (1998). The whole landfill model is described in more detail in 5.6. Fly ash and bottom ash are modelled separately since the leachability is differing for metals and some other substances. No gas formation is assumed in landfilling of ashes and no emissions due to landfill fires are added. Energy use in compactors at the landfill site is excluded from these models. The exclusions are considered insignificant, since their amounts are smaller than for similar flows within the incineration process.

Metal emissions during the surveyable time period of approximately 100 years originating from the bottom ashes are probably over-estimated because of non-updated data. The fractions leaching during the surveyable time period is anyhow small as are the total amounts so that this will not be influencing the results. Leakage from the landfilling of ashes is assumed to be treated in a municipal sewage treatment plant with following landfilling of the formed sludge, as described in section 5.6.2.

5.5.3 Allocations and system boundaries

A specific waste material is usually combusted as a part of a mixed waste and a problem arises concerning the allocation of emissions to the different waste fractions. In the incineration sub-model allocation is done either on a weight basis for a waste material or on an elemental basis, where elemental parameters describe a waste. The allocation methods used are thought to be best estimates (Björklund 1998).

Since the demand for energy recovered at the plant varies during a year, baling of the incoming waste is a storage option. Baling of waste is however excluded in this study. Consumption of energy and process additives are included. Production of the additives TMT 15 and Polyflock are excluded, due to lack of data. Process data for production of *urea*, *limestone B250* ($CaCO_3$) and *calciumhydroxide* are described in Appendices 1 and 5. The electricity consumed at the incineration facility, 0.28 MJ/ kg waste, is from coal power. Landfilling of the bottom ash and the fly ash, including transport work, are also included in the system.

A flow chart of the incineration system is shown in Figure 5.5.

5.5.4 Material specific data for incineration

Generated amounts of ashes for the different waste materials are presented in Table 5.3. The clay (chaolin) in newspaper is assumed by us to be left in the slag after incineration. In the case of incineration of PVC we assume a best case for the additives DEHP (Dietylhexylftalat) and DOM (Dioktyltinmaliat), assuming that these components will be completely combusted.

Table 5.3 Generated amounts of ashes for the included waste materials in the study.

Waste material	**Bottom ash (kg/kg TS)**	**Fly ash (kg/kg TS)**
Food waste	$1.8 \cdot 10^{-1}$	$2.0 \cdot 10^{-2}$
Newspaper	$1.2 \cdot 10^{-1}$	$1.3 \cdot 10^{-2}$
Corr. Cardboard	$5.4 \cdot 10^{-2}$	$6.0 \cdot 10^{-3}$
Mixed cardboard	$5.4 \cdot 10^{-2}$	$6.0 \cdot 10^{-3}$
PE	$9.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
PP	$9.0 \cdot 10^{-4}$	$1.0 \cdot 10^{-4}$
PS	$2.0 \cdot 10^{-2}$	$2.2 \cdot 10^{-3}$
PET	$2.7 \cdot 10^{-2}$	$3.0 \cdot 10^{-3}$
PVC	$6.9 \cdot 10^{-2}$	$7.7 \cdot 10^{-3}$

A more thorough description of the incineration sub-model, describing all assumptions, calculations and data is presented in Björklund (1998).

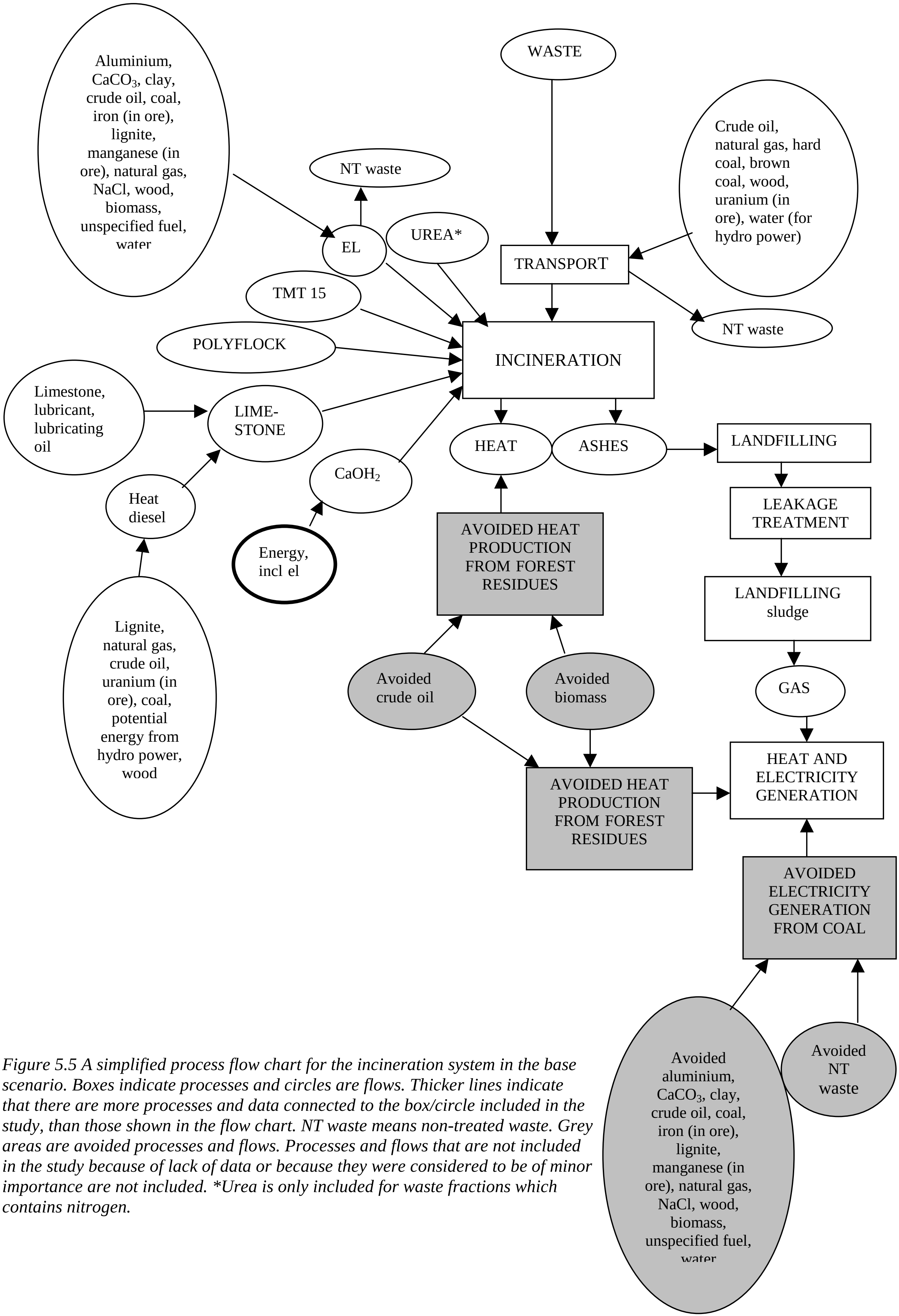

*Figure 5.5 A simplified process flow chart for the incineration system in the base scenario. Boxes indicate processes and circles are flows. Thicker lines indicate that there are more processes and data connected to the box/circle included in the study, than those shown in the flow chart. NT waste means non-treated waste. Grey areas are avoided processes and flows. Processes and flows that are not included in the study because of lack of data or because they were considered to be of minor importance are not included. *Urea is only included for waste fractions which contains nitrogen.*

5.6 Landfilling

5.6.1 General description

Landfilling is currently one of the most used waste treatment options in Sweden. There are about 300 municipal landfill plants and in 1998 4.8 million tonnes of waste (total amount) were treated at these plants (RVF 2000).

Environmental impacts from landfilling are spread over time. In contrast to other processes, e.g. incineration, emissions may well occur during several thousands of years. Emissions that our generation will not have to handle still have to be accounted for. In Finnveden (1992) the expressions *surveyable time period* (ST) and *remaining time period* (RT) are introduced. The surveyable time period is defined as the period until the landfill has reached a pseudo-steadystate (Finnveden et al. 1995). For landfilling of waste this is until the major part of the methane production has ceased. Surveyable time is usually around a century. The remaining time is the time that remains after the surveyable time period. When this time has passed all the components of the landfill has been released to the environment, a kind of worst case. For a discussion about how to handle the time aspects of landfill emissions we refer to Finnveden (1999c). The time perspective is also discussed in chapter 2.

5.6.2 The landfill model

The landfill model is based on the ORWARE sub-models for disposal of household waste, incineration ashes and sewage sludge described in Björklund (1998). This model describes an average Swedish municipal landfill. Emissions from landfilling are separated into emissions to water and to gas, and also in emissions occurring during the surveyable time period and those that occur during the remaining time period. Leachate purification and landfill fire data from Fliedner (1999) are added to some of the sub-models as described below. Landfills are assumed to have a collection system for gas operating during ST, with an efficiency of 50%. The gas collected is assumed to be combusted, gaining electricity and heat as described below. A simplified process flow chart for the landfilling system is presented in Figure 5.6. Following is a short description of the different *sub-models* of landfilling. A more thorough description and a presentation of emissions partitioning coefficients with references to primary sources are available in Björklund (1998). Inventory data derived from the model are presented in Appendix 5 for each process where landfilling is included.

Household waste

In the model for landfilling of *household waste* the different kinds of carbon are degraded at different rates. Biological carbon is divided into groups, where C-lignin is left non-degraded until RT, C-cellulose is degraded by 70% during ST and the rest of the biological carbon, easily degradable starch, sugar, fat and protein, is totally degraded during ST. Out of the fossil carbon, like for example in plastics, 97% is left within the landfill until the remaining time (Finnveden et al. 1995). Under the anaerobic conditions assumed for the surveyable time period various shares of the carbon is turned into carbon dioxide and methane depending on the origin of the carbon. During RT all fossil carbon is assumed to become CO_2. The only methane produced during RT is derived from 40% of the remaining cellulose carbon.

The major part of the nitrogen, chloride, potassium and calcium content of the household waste is emitted during ST, whereas most of the metals are left within the landfill until remaining time.

Emissions formed during landfill fires are added to the household waste sub-model. The leachate from the landfill is assumed to be purified in a municipal sewage treatment plant and sludge formed in the plant is landfilled. These processes are described below.

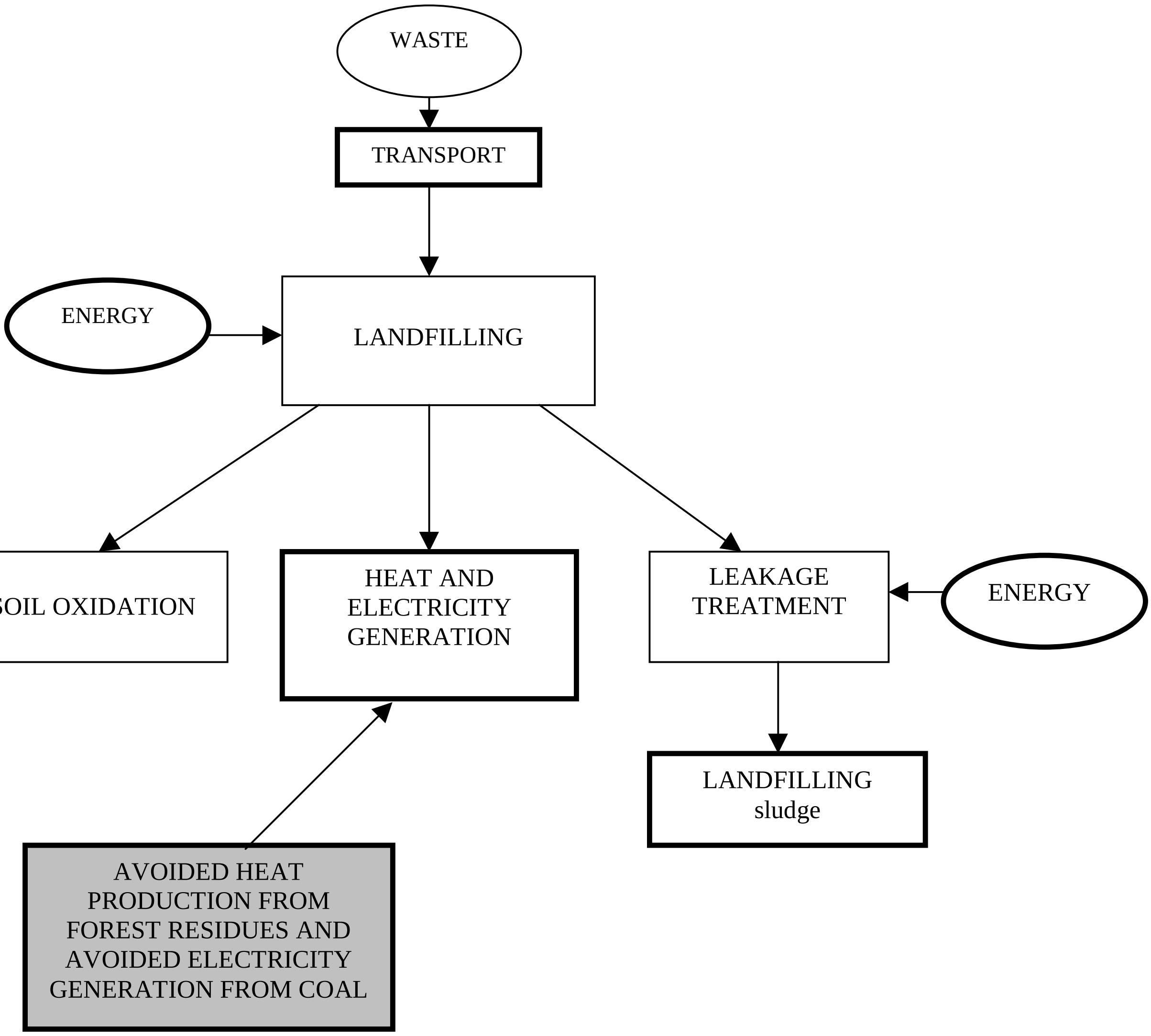

Figure 5.6 A simplified process flow chart for the landfilling system. Boxes indicate processes and circles are flows. Thicker lines indicate that there are more processes and data connected to the box/circle included in the study, than those shown in the flow chart. NT waste means non-treated waste. Grey areas are avoided processes and flows. Processes and flows that are not included in the study because of lack of data or because they were considered to be of minor importance are not included.

Sludge

The sludge landfilled in this study is mainly from the landfill leachate treatment but also from treatment of outgoing water from some recycling processes and composting. For *sludge* the same sub-model as for household waste is used, with the exception that phosphorus leakage is higher for sludge. Sludge is assumed to be landfilled mixed with household waste. No emissions due to landfill fires are added. We have delimited the system under study by excluding leachate treatment from the landfilling of sludge. Energy use by compactors at the landfill site is excluded from this sub-model. The exclusions made are considered insignificant, since their amounts are smaller than for similar flows within the total waste management system.

Landfill fires

Landfill fires frequently take place, 0.5 to 1 times per year and landfill, and the amount of uncontrolled burnt waste is estimated to 25 000 tons/year (Bergström and Björnes 1994). Emission factors for domestic waste landfill fires from Fliedner (1999) and Sundqvist (1999) are used. These are allocated to the combustible part, which is also suitable in this study. Only the emissions of chlorobensen, dioxins, PAH, PCB and Hg are documented. Fliedner and Sundqvist assume that only 25% of the emissions from landfill fires will actually become air emissions, since the rest will fall back down on to the landfill and this figure is also used here. Emissions of chlorobensen are here handled as adsorbable halogenated organic material, AOX. The data on emissions from landfill fires used are for household waste and fires occur during ST. In the future improved landfill technology will probably lower the frequency of landfill fires (Sundqvist 1999).

Leachate treatment

Leachate from the landfill contains nutrients, metals and other substances, which may have negative impacts on the environment. Water leaking from the landfill is therefore collected and treated before it is released to the recipients. Nielsen and Hauschild (1998, p 160) make an assumption that 80% of the leachate from the landfill is collected and the remaining 20% will leak to aquatic recipients. Here, the same assumption is used. The collected leakage is transported to a municipal waste water treatment plant, no resource uses or emissions connected to this transport is included. Leachate from the landfilling of household waste and of ashes from incineration are handled the same way. The leachate treatment plant removal factors are from Fliedner (1999, p VI) ”reduction in municipal leachate treatment” and are presented in Table 5.4.

Table 5.4 Reduction factors for waste water treatment plant (Fliedner 1999, p VI-VIII).

Substance	Reduction factor
AOX	0.4
BOD	0.944
COD	0.944
N-tot	0.4
N-NH_3/NH_4	0.8 *
N-NO_3	0.5
P	0.834
Cu	0.5
Pb	0.8
Cd	0.5
Hg	0.8
Cr	0.6
Ni	0.4

*Ammonia is transferred into nitrate, of which 50% is reduced to N_2 and released to the atmosphere.

Reduction of nitrogen is achieved through conversion to nitrogen gas released to the atmosphere. 50% of the nitrate is converted, the remaining 50% of the nitrate is assumed to be emissions to water.

Purifying the leachate demands 0.001 MJ/ kg water and 2 litres of leachate is assumed to arise from 1 kg of waste (Fliedner 1999, p 68). This figure is used for all fractions of waste. The energy used for purification is assumed to be electricity and the source of this electricity is coal.

The sludge from the leakage treatment is landfilled. When landfilling the sludge, the leachate purification step is excluded. To get the carbon content of the sludge the COD value is divided by three as a rule of thumb (Björklund 1998) and the carbon is assumed to be easily degradable. The amount of carbon in the sludge is very small compared to the carbon content of the waste handled and therefore this approximation will not be of importance.

Landfill gas

During the anaerobic degradation process within a landfill gas is formed. This gas is mainly methane and carbon dioxide, which are both potent greenhouse gases. To avoid emissions of these and simultaneously gain energy, landfill gas is collected and used for energy generation. In the model the landfill gas is combusted to gain heat and electricity, figures for modelling this process is from Dalemo (1997, p 16) and Björklund (1998, Appendix D). The energy gained is transferred into 60% heat and 30% electricity, 10% will be lost. Emissions from the combustion, CO_2, CH_4, NMVOC, CO, NO_x, N_2O, SO_x and Hg, are added to the inventory data. The CO_2 thus formed from CH_4 is divided into biological CO_2 and fossil CO_2 depending on the origin of the methane-carbon.

The energy content of the gas collected is 50.1 MJ/kg CH_4. Degradation of different carbon containing materials has different methane formation potentials. CH_4/CO_2 ratios for the biological carbon fractions are taken from Björklund (1998) and for the fossil sources from Sundqvist (1999, p 93). The latter ratios are defined for PE, PS, PET and PVC, we have assumed the PE-value for other plastics.

The amount of energy produced will be credited the landfill process as avoided energy production from another energy source. This other energy source varies between the scenarios.

It is not possible to trap all of the gas formed, and an efficiency of 50% of the gas emitted during ST is assumed. Gas that is not collected will pass through the soil where 15% of the methane is assumed to be oxidised to carbon dioxide. The CO_2 hence converted from CH_4 is divided into biological CO_2 and fossil CO_2 depending on the origin of the carbon in the methane.

Transports and energy

Data on transport modes and distances relevant for collecting and transporting waste for landfilling are presented in section 3.4.

Compactors are used at the landfill and they consume 0.04 MJ diesel per kg waste (Björklund 1998 and Eggels and van der Ven 1995). The data used here are an approximation using data for the process *diesel changing load*, which is described in Appendices 1 and 5.

5.6.3 Landfill as carbon sink

Emission data for landfilling are reported roughly specifying the time of expected release. This is done according to factors presented in Björklund (1998) separating emissions into those occurring during the surveyable time period (ST) and those that are released during the remaining time (RT). When only considering the surveyable time period emissions occurring later are not included in the system. Biological carbon then remaining within the landfill can be considered as caught in a carbon trap. This carbon sink concept is described further in 2.2.5.

Table 5.5 Amount of carbon, as CO_2, contributing to the landfill carbon sink.

Material	**Biological carbon as CO_2 left in landfill until RT**
Food waste	0.22 kg CO_2/kg waste
Newspaper	0.84 kg CO_2/kg waste
Corrugated board	0.76 kg CO2/kg waste
Mixed cardboard	0.59 kg CO2/kg waste

The waste fractions in this study containing biological carbon and thus the ones that will be affected by this concept are food waste, newspaper, corrugated cardboard and mixed cardboard. The amount of biological carbon remaining in the landfill until RT differ between the fractions depending on the degradability of the carbon and on the amount of the fraction in the household waste under study. The amounts are shown in Table 5.5. These amounts of CO_2 are, in the case of a limited time perspective and with the assumption that the landfill is considered as a carbon sink, inventoried as negative CO_2 emissions contributing to decreased values for the impact category global warming.

5.6.4 Other landfilling options

Biocells

There are other landfill opportunities, for example so called biocells. These have more efficient collection of the leachate and gas formed. Different types of waste are separately deposited, which gives the opportunity to reuse landfilled pure organic waste as fertiliser (compare with digestion). In biocells daily covers are not used. This gives increased landfill space, but may also increase odour emissions from organic waste in the landfill.

Biocells are not included in this study, but this could be done in future studies. For more information on biocells see e.g. Fliedner (1999).

5.7 Electricity production

5.7.1 Electricity from hard coal

The marginal electricity production is based on coal, according to the assumptions made in this study (se section 3.2). Data on electricity production from hard coal in a modern coal condensing power plant is taken from Frees and Weidema (1998). The efficiency of the power plant is 47 % and the lower calorific value of the coal considered is 24.3 MJ/kg. Data on emissions of SO_2, NO_x, and particles upon combustion is taken from Frischknecht ed. (1996) where they are calculated from emission limits as defined in EU 88/603 (European Commision 1988). The CO_2 emission is calculated using the value 94g CO_2 per MJ lower calorific value (Eurostat 1997). Other emissions are taken from Frischknecht et al. (1994).

For the extraction of coal Frees and Weidema use data from Frischknecht et al. (1994). Except for methane stemming from under ground mines, all air emissions come from energy use. Water emissions are caused by impurities and trace elements in the raw coal and may vary with the origin of the coal. According to Frees and Weidema the heavy metal emissions seem very uncertain.

5.7.2 Exceptions

Marginal electricity is used in most major processes in this study and in all cases where waste management leads to avoidance of electricity production from another source. Electricity used within the incineration facility, for anaerobic digestion, composting and for the recycling of all fractions, including the mixed plastics recycling for use in plastics palisades are modelled as marginal coal. The same is done for virgin production of the paper fractions. The data for virgin production of PET origin from APME (Boustead 1995) and are modified by Person et al. (1998) in that electricity reported as originating from hydro- and nuclear power are instead calculated as generated in coal power plants. Other electricity is mostly from fossil-fuelled plants. APME is also the original source of the data for the other virgin produced plastics (Boustead 1993, 1997a, b). Resources used and emissions from electricity use are in this case aggregated and the electricity assumed is a European mix. The mix differs and depends on the countries wherein the plastic production occurs. Fossil fuels are the main source.

In the secondary processes, the processes behind each waste management alternative (additives, transports and energy) where data are mostly obtained from existing databases no modifications are made. In many of these the electricity which is assumed is a European mix, including the European countries except the British Isles (called *UCPTE electricity*). The approximate composition of this mix is that half is obtained from nuclear and hydropower and the other half from fossil fuelled power plants.

5.8 Transports

5.8.1 Introduction

As far as possible we have aimed at using the same data on transports throughout the entire system studied. The data thereby used is briefly described below. For processes where the data is aggregated, the transport data provided is used (see the process descriptions in this chapter). Regarding sub-processes of minor importance, for which data are taken from the Sima Pro databases, the transport data used there is kept unchanged. The data concerning these transports is described in Appendices 1 and 5.

5.8.2 Trucks

Data on resource use and emissions connected to road transports by truck are taken from Frees and Weidema (1998). Data is available for rural, highway and urban driving conditions with light truck (14 ton total), medium sized truck (24 ton total) and heavy trucks (40 and 54 ton total). Frees and Weidema have collected and verified their combustion data from a few different sources but the basis is CORINAIR (1996). Fuel consumption for different sizes of trucks are supplied by Volvo (de Val 1992) and updated by Rydberg (1997). Volvo has not provided fuel consumption for all driving modes of each truck and the fuel consumption is therefore adjusted with factors from CORINAIR (1996). Emission factors from CORINAIR (1996) are used, updated with the emission standards given by the EU 1 norm (European Commision 1993). An efficiency of the engine of 33% is assumed. According to Frees and Weidema this is a, maybe somewhat conservative, average efficiency for a diesel truck engine. The precombustion data is taken from Frischknecht et al. (1994) and covers exploration, extraction, refining and transport to stock of the diesel fuel.

5.8.3 Garbage truck

Data for the fuel consumption of a garbage truck is taken from Sonesson (1997). In the city of Uppsala the fuel consumption during the collection route is stated to be 1057 MJ diesel per day. The collected amount of waste is 7.9 ton per day. It can thus be calculated that 0.134 MJ diesel is required for each kilogram of waste collected. In order to limit the number of data sources used for production and combustion of diesel, we use truck, urban driving from Frees and Weidema (1998) to represent the resource use and emissions of the garbage truck. This source also contains more data than Sonesson, for example on heavy metal emissions.

Transport from point A to point B with the garbage truck requires 4.4 MJ/tonkm according to Sonesson (1997). A maximum load and a one way distance are used when calculating the transport work performed, empty return is included. For resource use and emissions we use the data for diesel truck, rural driving from Frees and Weidema (1998).

5.8.4 Passenger car

For transports with private car we have used data for *Passenger car B250* from the BUWAL database available in Sima Pro. The reference is to BUWAL 250 (BUWAL 1998) where data has been summarised from Frischknecht et al. (1994) and Frischknecht et al. (1995). We have also consulted Frischknecht (1996) which is an update of Frischknecht et al. (1994) and Frischknecht et al. (1995) for a specification of metal emissions, in the BUWAL database referred to as metals and metallic ions.

The fuel used is assumed to be 20 % diesel and 80 % unleaded petrol. The data contains detailed emission data for production of diesel and petrol in Europe, including production and transport of primary energy sources excluding the infrastructure of the energy systems. The energy system used is the average of Western European countries in 1993 (BUWAL 1998).

5.9 Heat production

5.9.1 Introduction

The inventory data for heat production from forest residues, natural gas and heating oil is divided into the modules; production and distribution (Vattenfall 1996) and heat production (Boström 1998) as reported in Uppenberg et al. (1999 p. 4, 29, 36-37, 44-45, Teknisk bilaga; p. 39-40, 75-76).

National average values for heat production at district heating plants (gasification and combi-cycle) with a capacity of 50 to 300 MW are used, according to Boström C.Å. et al (1998). The efficiency of the biofuel plant is 1.06 and for the fossil fuel plant, 1.04 for natural gas and 0.91 for heating oil. The high efficiency values are achieved through flue gas condensation, the high moisture content in the biofuel and the high hydrogen content in the gas. The lower heating value (LHV) for the fuels are 8.4 MJ/ kg for biomass, 51.9 MJ/kg for natural gas and 41.4 MJ/kg for heating oil (Energiförsörjning 1996).

5.9.2 Residues of timber felling

For heat production from residues of timber felling, the biomass is transported 50 km from the forest to a district heating plant, Blümer (1997). The load factor is 0.5 and the moisture content of the biomass is 50%. Production and transport of NH_3, used for purification of air emissions generated at the district heating plant are included in the inventory data. Resources from nature are biomass (residues of timber felling) and oil. Oil here includes oil, petrol, diesel, lubricating- and transformer oil.

Combustion of biomass is not considered to give any net emissions of CO_2. For a discussion on this assumption see 2.2.5. The residual products from heat production, as reported by Uppenberg et al. (1999) are assumed to be ashes. Concentrations of the metals (Cd, Cr, Cu, Hg, Ni, Pb, Zn, B and As) in the ashes are from Rosén-Lidholm et al (1992 table 9:8, p.97). These figures are for bottom ashes, but since the concentration of the different metals in both bottom- and fly ashes are similar (Rosén-Lidholm et al. 1992), the fly ash values are assumed to be the same. Ashes are assumed to be retrieved to the forest (Vattenfall 1996) and the metals are assumed to be completely emitted to the soil during the remaining time period. Data for nutrient or trace elements in the ashes are not included in this study. For more information on nutrients in ashes, see Rosén-Lidholm et al (1992).

5.9.3 Natural gas

Natural gas is another resource used for heat production. In the original data used for this process, electricity for production and distribution is produced from hydro and nuclear power. This is changed to coal power according to the assumptions of the study. The energy carriers used as fuel are biomass, natural gas, oil and coal. The oil includes oil, petrol, diesel, lubricating- and transformer oil. Other resources from nature are natural gas, wood and iron ore. The residual products include residuals from manufacturing of materials and chemicals etc. These are handled as non-treated waste in the characterisation step.

5.9.4 Heating oil

The inventory data for production and distribution of heating oil refer to heating oil, type 1 and for heat production, the inventory data refer to heating oil, type 2-5 with a sulphur content 0.36% (Uppenberg et al. 1999). Electricity used for production and distribution is produced from hydro and nuclear power in the original data. This is changed to be coal power according to the assumptions of this study. The energy carriers used as fuel for production and distribution are biomass, natural gas, oil and coal. The oil includes oil, petrol, diesel, lubricating- and transformer oil. Resource from nature is iron ore. The residual products include residuals from manufacturing of materials and chemicals e t c, which are characterised as non-treated waste.

6 Impact assessment

6.1 Introduction

The impact assessment is carried out mainly according to established procedures in guidelines (Lindfors et al. 1995) and standards (ISO 1999) (see chapter 2 for general methodology). The impact assessment includes a classification and characterisation step (the characterisation methods are described in section 6.2) and two different weighting methods, Ecotax 98 (described in section 6.3) and Eco-indicator 99 (described in section 6.4). The characterisation and weighting factors applied are shown in Appendix 2. The list of characterisation factors found there also shows which substances that are classified into which impact categories.

6.2 Characterisation methods

6.2.1 Energy

Energy inputs are analysed as total energy as well as divided according to primary energy carrier into renewable and non-renewable. Hydropower, windpower, biogas and biomass are considered as renewable energy. Non-renewable energy is derived from coal, hard coal, brown coal (lignite), crude oil, natural gas, peat and uranium. The terms unspecified energy, energy recovered and fuel unspecified occurring in the inventories are listed separately since it is difficult to determine what they are made out of.

The inventory data is sometimes presented as a mass or volume of a fuel rather than as energy. These masses and volumes are converted to MJ based on the energy contents of the fuels. As far as possible we have tried to use the energy content used in the original data as higher heating value (Energiförsörjning 1996, BUWAL 1998, Frees and Weidema 1998).

6.2.2 Abiotic resources

Abiotic resources are analysed with respect to the exergy content in the materials according to a characterisation method presented by Finnveden and Östlund (1997).

6.2.3 Non-treated waste

Waste should preferably not be included as an impact category in LCA, since the waste has not yet left the technical system. Ideally the waste should be followed through the waste handling system so that inputs and outputs occurring there could be recorded in the inventory. This is not always the case and where different waste fractions appear in the inventories they are just added together by mass regardless of what they consist of. An exception is radioactive waste, which is not characterised in this study.

6.2.4 Global warming

To classify and characterise the contribution of greenhouse gases, global warming potentials (GWP) from IPCC (Houghton et al. 1996) are used for the time frames 20, 100 and 500 years. The global warming potentials are presented as CO_2-eqiuvalents. Values for chloroform, methylene chloride, and trifluoroiodomethane are added from Albritton et al. (1996). In the standard calculations the 100-year time frame is used. In one scenario, the other time perspectives are tested.

6.2.5 Stratospheric ozone depletion

For classification of stratospheric ozone depletion, a list over ozone depletion potentials (ODP) is used (Solomon and Wuebbles 1995), with addition of halons 1202 and 2401 and the HBFCs 1201, 2401 and 2311 from Pyle et al. (1991), both cited in Hauschild and Wenzel (1998b). Since all ozone depleting substances have the same weight according to Ecotax 98 no characterisation is made.

6.2.6 Photo-oxidant formation

Photo oxidant formation is represented by photochemical ozone creation potentials (POCP), available for volatile organic compounds (VOC) in different background concentrations of NO_x. We use POCP-values for ordinary Swedish background from Finnveden et al. (1992).

Hauschild and Wenzel (1998a) present average POCP values for VOC mixtures from various sources. In the low NO_x scenario, corresponding to Scandinavian conditions, the POCP for car exhausts is 0.5, for vapour from a car it is 0.4, for burning wood or twigs 0.6, for refining and distribution of oil it is 0.4 and for controlled landfilling of household waste it is 0.007. We assigned the POCP-value 0.5 to substances summarised under the names non-methane VOC and VOC in the inventories as well as to a variety of unspecified hydrocarbons and xylene (see Table 6.1). A POCP of 0.007 for methane is taken from a model with higher NO_x background (Derwent and Jenkin 1990 cited in Hauschild and Wenzel 1998a).

Table 6.1 The assigned photo-chemical ozone creation potentials (POCP) to substances and groups of substances not covered by Finnveden et al. (1992).

Emissions (as they occur in the inventories)	Assigned POCP
Aldehydes	0.5
Alkanes	0.5
Alkenes	0.5
AOX	0.5
Aromates C9-C10	0.5
Benzo(a)pyrene	0.5
CHX	0.5
CxHy	0.5
CxHy (aliph)	0.5
CxHy (alkenes)	0.5
CxHy (arom)	0.5
CxHy (non methane)	0.5
CxHy (oil)	0.5
CxHy aromatic	0.5
CxHy chloro	0.5
CxHy halogenated	0.5
CxHy polycyclic	0.5
Hydrocarbons	0.5
Methane	0.007
Non-methane VOC	0.5
Non-methane hydrocarbons	0.5
PAH	0.5
VOC	0.5
Xylene	0.5

6.2.7 Acidification (excluding SO_x and NO_x)

Acidification is characterised according to a method suggested by Finnveden et al. (1992), as presented in Lindfors et al. (1995), where the acidifying effect is defined as the amount of protons released in a terrestrial system. The acidifying potentials, expressed as equivalents of SO_2, are the ones used here. A max and a min scenario is suggested, where in the min scenario nitrogen compounds are not at all assumed to contribute to acidification.

Using a similar method, Hauschild and Wenzel (1998c) have calculated the acidifying potential of some additional substances. Values for H_2S, H_3PO_4, HCl, HF, and HNO_3 are collected from this report. For the release of H_2S to water, we have assumed the same acidifying potential as H_2S released to air. The acidifying potential of emissions to water expressed as 'Acid as H^+' in the inventory has been calculated to 32.5 SO_2-equivalents.

Emissions of sulphur and nitrogen oxides are reported in separate categories, since this fit better into the weighting procedure using Ecotax 98. The weighting sub-step is described below in section 6.3.

6.2.8 Aquatic eutrophication (excluding NO_x)

Substances contributing to aquatic eutrophication are classified and characterised according to the oxygen demand when the biomass they build up is decomposed (Lindfors et al. 1995). In our calculations a maximum scenario is used where the oxygen depletion potential of both nitrogen and phosphorous compounds are considered at the same time. Nitrogen oxides are treated separately in a category of their own to better fit into the weighting system described in section 6.3.

6.2.9 NH_3

NH_3 released to water is given the same value as NH_4^+. Air emissions of phosphorous compounds are assigned the same values as when emitted to water. A value for P_2O_5 has been calculated according to mass balance.

6.2.10 Toxicological effects

Toxicological effects on ecosystems and human health are difficult to model and the uncertainty in this area is considerable. For this reason we have used two different methods for the classification and characterisation of these effects. The methods used are the Dutch model USES-LCA (Huijbregts 1999a) and the toxicity parts of the Danish EDIP method (Hauschild et al. 1998a, Hauschild et al. 1998b).

USES-LCA

USES-LCA is a multimedia fate model used to find out the environmental concentrations of chemicals after emission. The estimated exposure level following a substance release is compared to a no effect parameter of the substance. Effects on human health and terrestrial, aquatic and sediment ecosystems are each modelled for emissions to air, fresh water, seawater, agricultural soil and industrial soil. Toxicity potentials expressed as equivalents of 1,4-dichlorobenzene are presented for 182 substances (Huijbregts 1999a). We have used the toxicity potentials available from 12 October 1999, with updates for terrestrial ecotoxicity and human toxicity from 1 December 1999 (Huijbregts 1999b).

In most inventories it is not specified whether the emissions occur to sea or fresh water, or to agricultural or industrial soil. In our calculations we have assumed that emissions to water are emitted into fresh water and that emissions to soil are emitted to agricultural soil.

In the inventories emissions are sometimes given as groups of compounds rather than as specified substances. We have as far as possible tried to find a representative value for these groups among the substances for which a characterisation value is present in the USES-LCA method. Table 6.2 shows which substance each of these emissions is characterised as.

Table 6.2 Some emissions lacking a value for characterisation of toxicological effects according to the USES-LCA method are represented by the value of a specific substance. In some cases the substance with the worst toxicity potential is chosen to see if this significantly influences the results. In other cases a more moderate representative is chosen instead, but in general the values derived through the representatives are a little bit high. This may be seen as a precautionary measure, since we do not know exactly what the emissions consist of.

Emission	**Characterised as**	**Emission compartment**	**Selection**
Alkenes	Ethene	Water	Representative
Aldehydes	Formaldehyde	Air	Representative
AOX	Hexachloro-1,3-butadiene	Air, Water	Worst
Aromates C9-C10	Dimethylphtalate	Air, Water	Representative
CHX	Hexachloro-1,3-butadiene	Air, Water	Worst
Cr	Cr VI	Air, Water, Soil	Worst
CxHy	Benzene	Air, Water	Representative
CxHy (aliph)	Ethene	Air, Water	Representative
CxHy (alkenes)	Ethene	Air	Representative
CxHy (arom)	Benzene	Air, Water	Representative
CxHy (non methane)	Benzene	Air	Representative
CxHy (oil)	Benzene	Air	Representative
CxHy chloro	Hexachloro-1,3-butadiene	Air, Water	Worst
CxHy halogenated	Hexachloro-1,3-butadiene	Air	Worst
CxHy polycyclic	Cancerogenic PAH’s	Air	Worst
Dissolved organics	Benzene	Water	Representative
Dissolved substances	Benzene	Water	Representative
DOC	Benzene	Water	Representative
Heavy metals	Median of heavy metals	Air	Representative
HgOH	Hg	Soil	Representative
Hydrocarbons	Benzene	Air	Representative
Metallic ions	Median of metals	Water	Representative
Metals	Median of metals	Air, Water	Representative
Non methane VOC	Benzene	Air, Water	Representative
Non methane hydrocarbons	Benzene	Water	Representative
Oil	Benzene	Water	Representative
Organics	Benzene	Water	Representative
Organic substances	Benzene	Air	Representative
Other organics	Benzene	Water	Representative
PAH	Cancerogenic PAH’s	Air, Water	Representative
Phenols	Phenol	Water	Representative
Tributyltin	Tributyltinoxide	Water	Representative
VOC	Benzene	Air, Water	Representative
Dust (human toxicity only)	PM 10	Air	Representative
Particles (human toxicity only)	PM 10	Air	Representative
Particulates (human toxicity only)	PM 10	Air	Representative
Soot (human toxicity only)	PM10	Air	Representative

EDIP

In the EDIP method a rather simple fate model is used to determine the fraction of an emission that ends up and can contribute to toxicity in different environmental compartments. This fraction is combined with a biodegradability factor and then compared to a no effect parameter. The toxicity potentials are expressed as the volume of the compartment needed to dilute the emission into a no effect concentration. Acute and chronic ecotoxicity in water and chronic ecotoxicity in soil are considered for emissions to air, water and soil of 70 substances (Hauschild et al. 1998b). Human toxicity potentials are presented for 100 substances for exposure via air, water, soil and groundwater following emissions to air, water and soil (Table 6.3 shows the sub-categories used in the EDIP method) (Hauschild et al. 1998a).

As mentioned above emissions are sometimes presented as groups of compounds in the inventories. Where possible we have tried to find reasonable representatives for these groups also among the substances for which toxicity potentials are available in the EDIP method. In some cases individual substances has also been represented by a related substance. In table 6.4 it can be seen which substance each of these emissions are characterised as.

Table 6.3 Sub-categories under toxicological effects used in the EDIP method.

Sub-categories under toxicological effects used in the EDIP method		
Type of toxicity	Emission compartment	Exposure compartment
Chronic ecotoxicity	Air	Water
Chronic ecotoxicity	Air	Soil
Chronic ecotoxicity	Water	Water
Acute ecotoxicity in	Water	Water
Chronic ecotoxicity	Water	Soil
Chronic ecotoxicity	Soil	Water
Chronic ecotoxicity	Soil	Soil
Human toxicity	Air	Air
Human toxicity	Air	Water
Human toxicity	Air	Soil
Human toxicity	Water	Air
Human toxicity	Water	Water
Human toxicity	Water	Soil
Human toxicity	Soil	Air
Human toxicity	Soil	Water
Human toxicity	Soil	Soil

Table 6.4 Some emissions lacking a value for characterisation of toxicological effects according to the EDIP method are represented by the value of a specific substance. In general the values derived through the representatives are a little bit high. This may be seen as a precautionary measure, since we do not know exactly what the emissions consist of.

Emission	**Characterised as**	**Emission compartment**
Aldehydes	Formaldehyde	Air
Alkanes	Hexane	Air, Water
AOX (human toxicity)	Vinylchloride	Air, Water, Soil
AOX (ecotoxicity)	Chlorobenzene	
Chlorobenzenes	Chlorobenzene	Air, Water
CHX	Vinylchloride	Air, Water, Soil
CHX (ecotoxicity)	Chlorobenzene	
CN-	Hydrogen cyanide	Air, Water
Cl-tot (human toxicity)	Cl	Air
Cr (ecotoxicity)	Cr VI	Air
Cr (III) (human toxicity)	Cr	Air
Cr (III) (ecotoxicity)	Cr	Water
Cr (VI) (human toxicity)	Cr	Air
Cr (VI) (ecotoxicity)	Cr	Water
Crude oil	Benzene	Air, Water
CxHy	Benzene	Air, Water
CxHy (aliph)	Hexane	Air, Water
CxHy (arom)	Benzene	Air, Water
CxHy (non methane)	Benzene	Air
CxHy (oil)	Benzene	Air
CxHy chloro (human toxicity)	Vinylchloride	Air, Water
CxHy chloro (ecotoxicity)	Chlorobenzene	Air, Water
CxHy halogenated (human toxicity)	Vinylchloride	Air, Water
CxHy halogenated (ecotoxicity)	Chlorobenzene	Air, Water
CxHy polycyclic (human toxicity)	Benzo(a)pyrene	Air, Water
Cyanides	Hydrogen cyanide	Air, Water
Dissolved organics	Benzene	Water
Dissolved substnances	Benzene	Water
DOC	Benzene	Water
Heavy metals	Mean of heavy metals	Air
HF (human toxicity)	Flouride	Air
Hydrocarbons	Benzene	Air, Water
Metallic ions	Benzene	Water
Metals	Mean of metals	Air, Water
Non methane VOC	Benzene	Air
Non methane hydrocarbons	Benzene	Air
Oil	Benzene	Water
Organics	Benzene	Water
Organic substances	Benzene	Air
Other organics	Benzene	Water
PAH (human toxicity)	Benzo(a)pyrene	Air
VOC	Benzene	Air, Water
Xylene	Xylenes, mixed	Air, Water

6.2.11 Undefined substances

The inventories consist of a wide range of resources and emitted substances. The characterisation methods provide weighting factors for the ones most commonly encountered in LCA-studies and for which sufficient data has been available. There are thus a variety of resources and emissions not covered by the characterisation methods used, and this must be kept in mind when interpreting the results.

6.3 Weighting using Ecotax 98

The weighting method Ecotax 98 is based on environmental taxes and fees in Sweden in 1998. Taxes and fees often address a single substance. This tax or fee may be used to calculate weights for other substances belonging to the same impact category using their characterisation weights. This means for example that CO_2-equivalents have the same weight regardless of if they are made up of carbon dioxide or methane. In both cases the weight derived from the carbon dioxide tax is applicable since the damage is regarded to be equal no matter if it is caused by emissions of carbon dioxide or methane. The weighting factors used are taken from Johansson (1999), and listed in Table 6.5 along with a note regarding which tax or fee they were derived from.

Table 6.5 Weighting factors for Ecotax 98 derived from Swedish environmental taxes and fees in 1998.

Intervention	Weighting factor	Comment
Extraction		
Energy	0-0.14 SEK/MJ	Tax on energy.
Emission		
Non-treated waste	0.25 SEK/kg	Tax on landfilled waste (from 01 01 2000).
CO_2	0.37 SEK/kg	Tax on the carbon content in fossil fuels.
Ozone depleting substances	600 SEK/kg	Exemption fee for exemptions from the prohibition of ozone depleting substances.
NO_2	40 SEK/kg	Fee on emissions of NO_x from stationary incineration plants.
Nitrogen	12 SEK/kg	Tax on the nitrogen content of fertiliser. In reality the tax is 1.80 SEK/kg. Here it is counted per N leached, assuming a leakage of 15 %.
Sulphur	30 SEK/kg	Tax on the sulphur content of fossil fuels.
Benzene	10-100 SEK/kg	Exemption fee for high contents of benzene in petrol.
Lead	180-350 SEK/kg	Exemption fee for high contents of lead in petrol.
Cadmium	30 000 SEK/kg	Tax on contents of cadmium exceeding 5 g/1000 kg phosphor in fertiliser.
Pesticides	20 SEK/kg	Tax on the active substance in pesticides.

In order to trace the largest spans we have used three different combinations of characterisation and weighting factors, one minimum combination and two maximum combinations. The two maximum combinations are identical except for the characterisation methods used to assess toxicological effects. The weighting factors used are described below and summarised in Table 6.6.

Abiotic resources

In the minimum combination we have set the weight of resource use to zero. This is consistent with the energy tax being zero for some activities and also with the opinions of some who think that resources should not be included in a life cycle impact assessment (this is for example the case in some LCA weighting methods, for example the individualist version of the Eco-indicator 99 described below and the XLCA (Newell 1998). In the maximum scenario the weighting factor derived from the energy tax on natural gas, 0.14 SEK/kg, is used.

Non-treated waste

All waste that has not been followed to the system boundary between the technical system and nature in the inventories is assigned the weight 0.25 SEK/kg.

Global warming

For global warming characterisation factors for the 100-year time frame and the weighting factor 0.37 SEK/kg CO_2 is used in all three combinations.

Stratospheric ozone depletion

All ozone-depleting substances have the weight 600 SEK/kg in all three combinations. No characterisation is thus performed.

Photo-oxidant formation

In the minimum combination the weighting factor 10 SEK/kg benzene is used and in the maximum scenarios we use 100 SEK/kg benzene. The weighting factors are calculated from the exemption fee on high levels of benzene in petrol. The lower weighting factor is based on the emissions of benzene from a car without catalytic cleaning, while the higher is valid for a car with catalytic cleaning (for calculations and references see Johansson (1999)).

Acidification (excluding SO_x and NO_x)

In the minimum combination nitrogen compounds are not considered, while in the maximum combinations they are. The weighting factor used in all three cases is 30 SEK/kg sulphur. NO_x and SO_x are treated separately.

Aquatic eutrophication (excluding NO_x)

In all three combinations aquatic eutrophication is characterised according to the assumption that both nitrogen and phosphorous compounds may eventually contribute to aquatic eutrophication. The weighting factor 12 SEK/kg nitrogen is used in all cases. NO_x is treated separately.

SO_x

Emissions of SO_x have the weight 30 SEK/kg sulphur in all the three combinations.

NO_x

Emissions of NO_x have effects in several impact categories and since they have their own weighting factor, 40 SEK/kg NO_2 they are kept in their own category, which is the same in all combinations.

NH_3

The contribution to terrestrial eutrophication from emissions of NH_3 is considered in a separate category since the other major contributor, NO_x, has been given its own category. The NH_3 emissions have the weight 12 SEK/kg N in the minimum combination. This is based on the weighting factor 12 SEK/kg nitrogen leached. In the maximum combinations the weight is 130 SEK/kg NH_3 based on 40 SEK/kg NO_2, assuming that the fee can be accounted per nitrogen content.

Toxicological effects

Two methods for assessing toxicological effects are used. For the USES-LCA method minimum and maximum weights are used. For the EDIP method only one set of weights is used in combination with the maximum case. Pesticides are put in its own category where the weight is 20 SEK/kg in all combinations.

***USES-LCA*.**

For effects on terrestrial ecosystems according to the USES-LCA method the weight 30 000 SEK/kg cadmium, emitted to agricultural soil, is used in both the minimum and the maximum scenarios. Effects in aquatic and sediment ecosystems have the weight 20 SEK/kg copper (copper is used as an anti-fouling agent under boats, and is thus subject to the tax on pesticides) as emitted to sea water in the minimum combination and 30 000 SEK/kg cadmium emitted to agricultural soil in the maximum combination. For effects on human health the weight 10 SEK/kg benzene emitted to air is used in the minimum combination and in the maximum combination the weight 30 000 SEK/kg cadmium emitted to agricultural soil is used.

***EDIP*.**

For chronic eco-toxicological effects in water after emission to air the weight 350 SEK/kg lead is used in the EDIP method. For acute and chronic effects in water after emission to water we use the weighting factor 20 SEK/kg copper. Chronic ecotoxicity in soil after emissions to soil have the weight 30 000 SEK/kg cadmium. Human health effects through air, water and soil exposure from toxic emissions to air are weighted with the factor 100 SEK/kg benzene. For effects from water exposure after toxic releases to water the weight 20 SEK/kg copper is applied and for effects through exposure via soil from emissions to soil 30 000 SEK/kg cadmium is used.

To be able to assign weights to a category a substance for which there is a weighting factor must be present among the substances having a characterisation value. This means that for toxicological effects a characterisation value for cadmium, benzene, lead or a pesticide must be available. This is not the case for chronic eco-toxicological effects in soil after emissions to air or water and for chronic ecotoxicity in water after emission to soil. These categories are therefore given a zero weight. For the same reason the weight of effects on human health is set to zero for emissions to water with effects through air and soil and for the effects of soil emissions through water and air.

Table 6.6 The weights used in the minimum and maximum combinations.

Impact category	Combination	Weighting factor	Reference of the characterisation method	Weight of reference
Abiotic resources	Min	0 SEK/MJ	MJ	0 SEK/MJ
	Max	0.14 SEK/MJ	MJ	0.14 SEK/MJ
Non-treated waste	Min/max	0.25 SEK/kg waste	Waste	0.25 SEK/kg
Global warming	Min/max	0.37 SEK/kg CO_2	CO_2	0.37 SEK/kg
Stratospheric ozone depletion	Min/max	600 SEK/kg ozone depleting substance	All ozone depleting substances	600 SEK/kg
Photo-oxidant formation	Min	10 SEK/kg benzene	Ethene	24.9 SEK/kg
	Max	100 SEK/kg benzene	Ethene	249 SEK/kg
Acidification (excl. SO_x and NO_x)	Min/max	30 SEK/kg S	SO_2	15 SEK/kg

Table 6.6 continued…

Impact category	Combination	Weighting factor	Reference of the characterisation method	Weight of reference
Aquatic eutrophication (excl. NO_x)	Min/max	12 SEK/kg N	kg O_2 demand/kg emission	0.6 SEK/kg
SO_x	Min/max	30 SEK/kg S	SO_2	15 SEK/kg
NO_x	Min/max	40 SEK/kg NO_2	NO_2	40 SEK/kg
NH_3	Min Max	12 SEK/kg N 40 SEK/kg NO_2	N N	12 SEK/kg 130 SEK/kg
Toxicological effects	Min/max	20 SEK/kg pesticide	Pesticide	20 SEK/kg
- chronic terrestrial ecotox	EDIP emission to soil	30 000 SEK/kg Cd	m^3 soil/g	13 636 SEK*g/kg/m^3 soil
- acute aquatic ecotox	EDIP emission to water	20 SEK/kg Cu	m^3 water/g	0.015 SEK*g/kg/m^3 water
- chronic aquatic ecotox	EDIP emission to air	350 SEK/kg Pb	m^3 water/g	0.875 SEK*g/kg/m^3 water
- chronic aquatic ecotox	EDIP emission to water	20 SEK/kg Cu	m^3 water/g	$1.54*10^{-3}$ SEK*g/kg/m^3 water
- human health, exposure via air	EDIP emission to air	100 SEK/kg benzene	m^3 air/g	$1.0*10^{-5}$ SEK*g/kg/m^3 air
- human health, exposure via water	EDIP emission to air	100 SEK/kg benzene	m^3 water/g	43.5 SEK*g/kg/m^3 water
- human health, exposure via water	EDIP emission to water	20 SEK/kg Cu	m^3 water/g	1.176 SEK*g/kg/m^3 water
- human health, exposure via soil	EDIP emission to air	100 SEK/kg benzene	m^3 soil/g	7.14 SEK*g/kg/m^3 soil
- human health, exposure via soil	EDIP emission to soil	30 000 SEK/kg Cd	m^3 soil/g	5 357 SEK*g/kg/m^3 soil
- terrestrial ecotoxicity	USES min	30 000 SEK/kg Cd to agricultural soil	1,4-dichlorobenzene emitted to industrial soil	136 SEK/kg
- aquatic ecotoxicity	USES min	20 SEK/kg Cu to sea water	1,4-dichlorobenzene emitted to fresh water	$1.0*10^{-5}$ SEK/kg
- sediment ecotoxicity	USES min	20 SEK/kg Cu to sea water	1,4-dichlorobenzene emitted to fresh water	$3.8*10^{-5}$ SEK/kg
- human health	USES min	10 SEK/kg benzene to air	1,4-dichlorobenzene emitted to air	$5.3*10^{-3}$ SEK/kg
- terrestrial ecotoxicity	USES max	30 000 SEK/kg Cd to agricultural soil	1,4-dichlorobenzene emitted to industrial soil	136 SEK/kg
- aquatic ecotoxicity	USES max	30 000 SEK/kg Cd to agricultural soil	1,4-dichlorobenzene emitted to fresh water	0.20 SEK/kg
- sediment ecotoxicity	USES max	30 000 SEK/kg Cd to agricultural soil	1,4-dichlorobenzene emitted to fresh water	0.70 SEK/kg
- human health	USES max	30 000 SEK/kg Cd to agricultural soil	1,4-dichlorobenzene emitted to air	1.2 SEK/kg

6.4 Eco-indicator 99

In order to check the robustness of the results from the impact assessment, an additional impact assessment method is applied to the studied inventory data. The method called Eco-indicator 99, is available in the Sima Pro 4.0 software and is described by Goedkoop and Spriensma (1999). In this method endpoint modelling is used in the characterisation step. This means that damages on human health, ecosystem quality and resource stock are modelled. To tackle model uncertainties a system referred to as Cultural Theory has been used to separate three versions of the damage model corresponding to three different worldviews. The default version suggested by the authors corresponds to a Hierarcist perspective, embracing a balanced time perspective and consensus among scientists as the determining factor for the inclusion of effects. This version is the one used here. Included in the method is also a normalisation step mainly based on European data from 1990-1994. The weighting factors used have been derived through a panel procedure, with panellists from the Swiss LCA community. The panellists have been asked to rank the importance of the three endpoints human health, ecosystem quality and availability of resources.

6.4.1 Human health

Damage to human health is expressed as disability adjusted life years (DALY). The DALY are derived through estimates of the number of years lived disabled (YLD) and years of life lost (YLL). Models for respiratory and carcinogenic effects, effects of climate change, ozone layer depletion and ionising radiation are included.

6.4.2 Ecosystem quality

Damage to ecosystem quality is expressed as the percentage of species lost in an area due to the environmental load. The definition differs slightly between the three different impact categories included. Ecotoxicity is expressed as the percentage of species living under toxic stress (potentially affected fraction – PAF). Acidification and eutrophication are treated as a single impact category considering terrestrial effects only. The damage to target species of vascular plants in Dutch natural areas is modelled for this category. The impact category land-use and land transformation is based on empirical data on the occurrence of vascular plants as a function of land-use type and the size of the area.

6.4.3 Abiotic resources

Extraction of resources is related to an indicator of the remaining mineral and fossil resources. In both cases the damage from resource extraction is expressed in terms of the resulting higher energy requirements for future extraction.

6.4.4 Additions

For some substances occurring in the inventories not represented in the hierarcist version of Eco-indicator 99, approximations have been done. They are shown in Table 6.7.

Table 6.7 Some emissions lacking a value for characterisation of toxicological effects according to the Eco-indicator 99 are represented by the value of a specific substance. In general the values derived through the representatives are a little bit high. This may be seen as a precautionary measure, since we do not know exactly what the emissions consist of.

Emission	**Characterised as**	**Emission compartment**
AOX	Hexachlorobenzene	Air, Water, Soil
Chlorobenzenes	Hexachlorobenzene	Water
CHX	Hexachlorobenzene	Air, Water, Soil
Cr (human toxicity)	Cr(VI)	Water
Crude oil	Benzene	Water
CxHy	Benzene	Water
CxHy (arom)	Benzene	Water
CxHy chloro	Hexachlorobenzene	Air, Water
Dissolved organics	Benzene	Water
Heavy metals	Metals	Air
Hydrocarbons	Benzene	Water
Metallic ions	Median of metals	Water
Metals	Median of metals	Water
Oil	Benzene	Water
Organics	Benzene	Water

7 Results and discussion

7.1 Introduction

Results from the inventory analysis are shown in Appendix 6.

In this section, results from the characterisation and weighting elements are presented. The results from the characterisation have been multiplied with the corresponding weighting factors for Ecotax 98 described in chapter 6, Table 6.5. The results are therefore presented with the unit [SEK]. If the reader prefers to have the original units for the characterisation results, they can be obtained by back calculation using the same weighting factors. The Eco-indicator 99 results are only presented as total weighted results in the tables and the results are only shortly discussed.

Here the results are present both in tables and in text. Many readers will probably not like to read all details in this section at once but perhaps look at some tables, read chapter 8 and use this section as a reference for details of interest.

In this section, the results are presented for five different waste management strategies: landfilling, incineration, recycling of paper and plastic materials combined with either composting or digestion with the biogas used for heat and electricity or digestion with the biogas used as fuels for vehicles. The calculations for each of these strategies are made as if all of the yearly production of the waste fractions included is treated with the same strategy. The results are presented for the whole system, which is all waste fractions added together. For the base scenario each waste fraction is also presented separately and for most other scenarios results are presented for newspaper (as an example of a paper material), PET (as an example of a plastic material) and food waste. Results for all scenarios and all fractions are presented in Appendix 4.

The results for different waste fractions are dependent on their respective share of the whole system. Since the amounts are differing, the figures for different fractions are not directly comparable. If the reader wants the results per mass treated waste, this can be calculated using the amounts of waste presented in chapter 4.When interpreting the results, comparisons can be made with the rules of thumb of uncertainty for different impact categories suggested in Table 2.2. These rules of thumb are however not directly applicable on the results presented here. This is because we use subtracted systems sometimes resulting in negative results and therefore it is mathematically no longer possible to use rules-of-thumb expressed as percentages or factors. The rules-of-thumb can however still be used a rough guide when checking order of magnitude differences.

The only thing that differs between the three recycling cases is the treatment method used for food waste. To increase the readability of the tables the result from recycling of the other waste fractions are just presented once, under recycling combined with digestion with production of heat and electricity.

The contribution to the impact category stratospheric ozone depletion is very small and the results are not shown here but can be viewed in Appendix 7. In Appendix 7, more results from the characterisation are presented in which it is shown, from which substances the contributions to the final results are obtained. This also shows the classification into impact categories for the substances found in the inventories. Extracted materials and emissions made that are not covered by the characterisation methods used are listed as undefined substances. The undefined substances for the base scenario are discussed below and can be viewed in Appendix 3.

Sources for data on sub-processes such as energy, transport and additives are shortly presented in Appendix 1. More thorough descriptions, through inventory data records are available in Appendix 5, where all process data records are compiled.

In the below presentations of the results the focus is on the order in which the treatment alternatives turn out relative to each other in the different impact categories.

7.2 Results Base scenario

7.2.1 Total Energy

All treatments show net energy savings when looking at the whole system under study. This also holds true for each individual waste fraction, except for composting of food waste. Focusing on the whole system, most energy is saved in the recycling alternatives. Here the total energy balance is dominated by renewable energy from wood feedstock avoided when recycling paper. In the incineration alternative a little less energy is saved. The total energy balance for incineration is completely dominated by renewable energy from the avoided heat production from forest residues. The largest amount of forest residues is saved when incinerating the newspaper fraction. The least energy is saved in the landfill option. In the total energy balance for landfill non-renewable energy savings are somewhat larger than the savings of renewable energy. The non-renewable energy is mostly from coal in avoided electricity production and the renewable energy is biomass in avoided heat production.

For food waste most energy is saved in the incineration alternative. This is almost entirely renewable energy from avoided heat production from forest residues. Somewhat less energy is saved when digesting the food waste and using the gas derived for electricity and heat production, saving coal and biomass. Less energy is saved using the digester gas to fuel a bus. In this case it is non-renewable energy from diesel that is avoided. A little bit less still is the energy saved in the landfill alternative where coal and biomass in electricity and heat production are avoided. When composting the food waste energy is used, mostly non-renewable energy in the form of crude oil to power machines.

The recycling alternative for newspaper saves energy, predominantly renewable energy in the saved wood feedstock but also some non-renewable energy from coal in the avoided virgin paper production. Less energy is saved using the incineration option. The savings are biomass in the avoided heat production from forest residues. A net expenditure of non-renewable energy from coal used at the incineration plant also influence the result. The least energy is saved when landfilling. It is non-renewable energy from coal and renewable energy from biomass from avoided electricity and heat production that are the major sources of these savings.

Table 7.1 The results for total energy and non-renewable energy are shown in MJ/year. For abiotic resources and non-treated waste the weighted result is shown in SEK/year. Within these impact categories the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	Base scenario									
	Whole system	Food waste	Newspaper	Corrugated cardboard	Mixed cardboard	PE	PP	PS	PET	PVC
Total energy										
Rec dig h/e	-3.8E+10	-2.2E+09	-2.2E+10	-4.0E+09	-2.5E+09	-6.0E+09	-6.3E+08	-5.2E+08	-4.4E+08	-1.1E+08
Rec dig f	-3.8E+10	-1.5E+09								
Rec comp	-3.6E+10	4.3E+08								
Incineration	-2.2E+10	-2.7E+09	-7.9E+09	-3.7E+09	-2.2E+09	-4.3E+09	-5.8E+08	-4.0E+08	-1.4E+08	-7.8E+07
Landfill	-5.2E+09	-1.2E+09	-1.8E+09	-5.6E+07	-5.9E+08	-1.6E+09	-8.5E+06	-5.3E+06	-8.5E+05	-3.9E+05
Non-renewable energy										
Rec dig h/e	-1.5E+10	-1.3E+09	-7.4E+09	4.0E+08	-3.2E+08	-4.8E+09	-3.9E+08	-3.8E+08	-4.4E+08	-7.6E+07
Rec dig f	-1.5E+10	-1.5E+09								
Rec comp	-1.3E+10	4.2E+08								
Incineration	4.8E+08	1.3E+08	2.4E+08	1.1E+08	6.8E+07	-4.8E+07	-6.7E+06	-3.1E+06	7.5E+05	1.8E+06
Landfill	-2.9E+09	-6.7E+08	-9.9E+08	-1.7E+07	-3.2E+08	-8.8E+08	-3.2E+06	-1.8E+06	1.8E+05	2.9E+05
Abiotic resources										
Rec dig h/e	-2.1E+09	-1.9E+08	-1.0E+09	5.8E+07	-6.6E+07	-6.8E+08	-5.5E+07	-5.3E+07	-6.2E+07	-1.1E+07
Rec dig f	-2.1E+09	-2.1E+08								
Rec comp	-1.8E+09	5.9E+07								
Incineration	7.0E+07	1.8E+07	3.4E+07	1.6E+07	9.7E+06	-6.3E+06	-8.9E+05	-3.9E+05	1.2E+05	2.6E+05
Landfill	-4.0E+08	-1.2E+08	-1.4E+08	-9.4E+07	-4.5E+07	-2.3E+06	-4.5E+05	-2.4E+05	2.5E+04	4.1E+04
Non-treated waste										
Rec dig h/e	-4.3E+07	-8.0E+06	-3.1E+07	-5.5E+06	3.9E+05	2.6E+06	1.4E+06	1.1E+06	-5.0E+06	4.0E+05
Rec dig f	-3.6E+07	-1.1E+06								
Rec comp	-3.7E+07	-2.2E+06								
Incineration	4.7E+06	7.2E+05	2.0E+06	9.2E+05	5.4E+05	4.2E+05	5.7E+04	4.5E+04	2.3E+04	1.7E+04
Landfill	-1.5E+07	-4.5E+06	-5.2E+06	-3.4E+06	-1.7E+06	-2.0E+05	-3.2E+04	-2.2E+04	-5.9E+03	-3.8E+03

For PET most energy is saved in the recycling alternative. The dominating post being non-renewable energy from crude oil as raw material in the avoided virgin PET production. In the incineration case less energy is saved in the form of renewable energy from avoided heat production from forest residues. Much less energy is saved using the landfill option, saving coal and biomass from avoided electricity and heat production. The low gas production in the landfill is due to a very low degradation rate for plastics.

7.2.2 Non-renewable energy

Looking at the whole system studied, net savings of non-renewable energy are made in the recycling and landfill alternatives while incineration show a net expenditure. In the recycling case the major contributors are coal for electricity in the avoided virgin newspaper production, and natural gas and oil as raw material in the avoided virgin production of PE. Concerning landfill, the savings are made up by coal from avoided electricity production. In the case of incineration, coal for electricity used in the incineration plant accounts for most of the non-renewable energy used.

Among the different options for handling food waste, digestion saves the most non-renewable energy. Using the digester gas for bus fuel, avoiding diesel fuel saves a little bit more than when using it for production of heat and electricity, where only the avoided coal for electricity production can be accounted for here. Some non-renewable energy is also saved in the landfill case, when coal for electricity production is avoided. For incineration electricity from coal, used in the incineration plant gives a net non-renewable energy expenditure. Composting the food waste gives rise to even more non-renewable energy use, mainly diesel for machines.

For the newspaper fraction, recycling saves most non-renewable energy since energy from coal in the virgin paper production can be avoided. Landfilling also allow some savings of non-renewable energy through avoided electricity production from coal. Incineration on the other hand uses non-renewable energy in that electricity from hard coal is utilised in the incineration plant.

Non-renewable energy can be saved through recycling PET, since crude oil as a raw material in virgin PET production is avoided. The landfill option shows a net use of non-renewable energy. Here diesel fuel mainly for transportation outweighs the avoided electricity production from coal, since there is only little landfill gas produced. For incineration the electricity from coal used in the power plant cause an even higher net non-renewable energy usage.

7.2.3 Abiotic resources

The impact from the use of abiotic resources follows the same pattern as the non-renewable energy balance. This would be expected since the characterisation method applied is based on the exergies of the resources, and most of the resources studied are in fact energy carriers. The results from the base scenario for abiotic resources are the same as for non-renewable energy (see above).

7.2.4 Non-treated waste

For the whole system more non-treated waste is avoided than is being produced in the recycling and landfilling cases, a bit less for landfill. Incineration causes a net generation of waste. It is mostly bulk waste from electricity production from coal that influences the results.

7.2.5 Global warming

From the greenhouse gas point of view recycling is the most favourable treatment option for all of the materials studied. Dominating the result for the whole system is avoided CO_2 emissions from coal produced electricity used in virgin newspaper production. In the incineration alternative there are net emissions of CO_2-eqivalents for all the studied waste fractions, since the avoided heat production is from bio-fuel. A major contribution to the total result comes from incineration of PE, which is the major fossil carbon containing waste fraction studied. Most emissions of CO_2-eqivalents are caused in the landfill case. These emissions mainly consist of methane released in the surveyable time period from the paper and food waste fractions.

For food waste a net avoidance of CO_2 emissions is made in the digestion alternatives, slightly more if using the digester gas as bus fuel than for heat and electricity production. Composting gives a net emission of greenhouse gases of which CO_2 is the major part. A little bit more greenhouse gases are emitted in the incineration case. The largest contribution in this case comes from N_2O and a little less from CO_2 emissions. The landfill option gives rise to the highest net releases of greenhouse gases, mainly occurring in the form of methane emissions in the surveyable time period.

As stated above, recycling newspaper results in the avoidance of CO_2 emissions from electricity use in virgin paper production. Incineration causes net emissions of CO_2. The largest net emissions of greenhouse gases are made in the landfill alternative, mostly as methane in the surveyable time period.

Recycling PET gives a net avoidance of CO_2 emissions from the virgin production process. Incineration gives a net output of CO_2. A slightly higher emission is shown in the landfill alternative, mostly consisting of CO_2 released in the remaining time period.

Table 7.2 The table shows weighted results in the unit SEK/year. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	Base scenario									
	Whole system	Food waste	Newspaper	Corr. cardboard	Mixed cardb.	PE	PP	PS	PET	PVC
Global warming										
Rec dig h/e	-2.4E+08	-4.6E+07	-2.2E+08	-1.2E+07	9.4E+06	1.1E+07	1.1E+07	6.5E+06	-4.6E+06	2.4E+06
Rec dig f	-2.4E+08	-5.0E+07								
Rec comp	-1.8E+08	7.2E+06								
Incineration	2.1E+08	8.8E+06	1.0E+07	1.6E+06	3.3E+07	1.2E+08	1.6E+07	1.3E+07	4.9E+06	2.4E+06
Landfill	8.5E+08	1.5E+08	2.5E+08	1.6E+08	1.2E+08	1.3E+08	1.8E+07	1.5E+07	5.3E+06	2.7E+06
Photo-oxidant formation max										
Rec dig h/e	-2.0E+08	1.7E+07	-1.7E+07	2.1E+07	-1.6E+07	-1.5E+08	-1.5E+07	-2.9E+06	-3.6E+07	-6.4E+06
Rec dig f	-2.0E+08	2.4E+07								
Rec comp	-1.9E+08	2.3E+07								
Incineration	-1.1E+08	-1.2E+07	-3.9E+07	-1.8E+07	-1.0E+07	-2.3E+07	-3.1E+06	-2.1E+06	-7.3E+05	-4.0E+05
Landfill	3.2E+08	7.6E+07	1.2E+08	7.6E+07	3.7E+07	5.4E+06	7.2E+05	5.2E+05	1.8E+05	1.3E+05
Acidification (excl SO_x and NO_x)										
Rec dig h/e	-2.9E+06	-1.9E+05	-6.3E+05	-7.9E+05	-3.3E+04	-7.7E+03	-3.8E+05	-1.4E+05	-5.1E+05	-2.2E+05
Rec dig f	-2.7E+06	5.4E+03								
Rec comp	1.4E+06	4.1E+06								
Incineration	-1.2E+06	8.4E+04	-5.3E+05	-2.5E+05	-1.1E+05	-2.9E+05	-3.9E+04	-2.7E+04	-9.6E+03	-5.2E+03
Landfill	2.0E+05	4.7E+05	-1.6E+05	-1.1E+05	9.3E+03	-6.9E+03	-1.0E+03	-7.0E+02	-2.0E+02	-1.3E+02
Aquatic eutrophication (excl NO_x)										
Rec dig h/e	-2.3E+06	-3.2E+06	3.2E+05	-1.2E+06	-1.6E+06	3.4E+06	-1.1E+04	-4.6E+03	-1.6E+04	-2.3E+03
Rec dig f	-2.3E+06	-3.2E+06								
Rec comp	1.9E+06	1.0E+06								
Incineration	6.5E+07	5.8E+07	-6.0E+04	-2.0E+04	5.6E+06	1.6E+06	-8.8E+03	-5.5E+03	-3.3E+03	-1.1E+03
Landfill	9.5E+07	8.6E+07	6.2E+05	4.0E+05	8.6E+06	3.3E+04	4.4E+03	3.7E+03	1.4E+03	6.7E+02
SO_x										
Rec dig h/e	-3.5E+07	-3.5E+05	-1.1E+07	-9.8E+06	-4.7E+06	-5.2E+06	-9.4E+05	-7.4E+05	-2.1E+06	-3.4E+05
Rec dig f	-3.7E+07	-1.8E+06								
Rec comp	-3.7E+07	-1.8E+06								
Incineration	-1.0E+07	-2.3E+05	-4.2E+06	-2.0E+06	-6.6E+05	-2.5E+06	-3.4E+05	-2.3E+05	-8.0E+04	-4.2E+04
Landfill	2.2E+06	8.1E+05	6.3E+05	3.9E+05	3.2E+05	7.9E+04	8.3E+03	6.3E+03	2.8E+03	2.1E+03
NO_x										
Rec dig h/e	-8.3E+07	2.3E+06	-6.5E+07	1.8E+07	-8.4E+06	-2.3E+07	-8.8E+05	-1.2E+06	-4.4E+06	-6.5E+05
Rec dig f	-4.1E+07	4.5E+07								
Rec comp	-7.2E+07	1.4E+07								
Incineration	9.4E+06	2.2E+05	1.7E+07	-1.2E+06	-1.9E+06	-4.3E+06	-4.9E+05	-3.2E+05	-9.0E+04	2.3E+05
Landfill	6.5E+06	1.2E+06	2.6E+06	1.0E+06	6.4E+05	8.6E+05	1.1E+05	8.6E+04	4.4E+04	3.4E+04
NH_3 max										
Rec dig h/e	-1.6E+05	-2.2E+05	2.6E+05	2.7E+05	-9.5E+04	-2.6E+05	-6.1E+04	-4.3E+04	2.2E+02	-8.4E+03
Rec dig f	5.8E+04	2.7E+03	2.6E+05	2.7E+05	-9.5E+04	-2.6E+05	-6.1E+04	-4.3E+04	2.2E+02	-8.4E+03
Rec comp	1.6E+07	1.6E+07								
Incineration	-4.8E+06	2.6E+05	-2.2E+06	-1.0E+06	-4.6E+05	-1.1E+06	-1.5E+05	-1.1E+05	-3.8E+04	-2.1E+04
Landfill	1.9E+06	2.1E+06	-2.1E+05	-1.4E+05	1.6E+05	-1.0E+04	-1.3E+03	-8.9E+02	-2.4E+02	-1.6E+02

7.2.6 Photo-oxidant formation

Considering the whole system, recycling is the most favourable alternative in the photo-oxidant formation category. This option benefits mainly from the avoided emissions of VOC in the virgin production of PE. In the incineration alternative the avoided contribution to the category is a little bit less. CO and NMVOC from the avoided heat production dominate for all of the studied waste fractions. For landfill, the methane released in the surveyable time period, followed by methane released in the remaining period gives a net emission of photo-oxidant formatting gases.

For food waste, incineration is the only alternative where the net contribution to the photo-oxidant formation impact category is negative. Digesting the food waste and using the gas as bus fuel results in net emissions, the major part consisting of unspecified hydrocarbons from the bus use phase. A little bit more net emissions results when using the gas for heat and electricity production mainly recorded as NMVOC from heat production. The highest net emissions are found in the landfill case.

For newspaper, the emissions contributing to photo-oxidant formation avoided in the incineration case are larger than those avoided when recycling. Landfilling gives a net contribution to this impact category.

Recycling PET avoids more emissions of photo-oxidant formatting substances than does incineration. Landfill causes net emissions of these substances.

7.2.7 Acidification (excluding SO_x and NO_x)

When looking at acidification (excluding NO_x and SO_x), recycling and digestion gives a negative impact for all materials, except for food waste when the digestive gas is used to substitute diesel bus fuel. The incineration alternative also gives a net avoidance for all waste fractions except for food waste. Landfilling has a net contribution to acidification (excluding SO_x and NO_x). Recycling combined with composting has the largest contribution to the category, arising from NH_3 emissions from the composting process.

For food waste the only treatment option rendering an avoided contribution to this impact category is digestion with electricity and heat production. It is mainly emissions of HCl from electricity production from hard coal that is avoided. Digestion where using the gas as bus fuel shows the smallest contribution to the category followed by incineration, landfilling and composting.

For newspaper, all treatment options show negative results. The most from recycling a little bit less from incineration and the least from landfilling.

PET shows the same pattern as newspaper, only with greater differences between the different treatments.

7.2.8 Aquatic eutrophication (excluding NO_x)

For the whole system recycling combined with digestion shows a net avoidance of emissions contributing to eutrophication (excluding NO_x) In combination with composting there is a net contribution, however, smaller than for incineration, which in turn has a smaller contribution than landfilling.

The results for the food waste fraction are similar to that of the whole system.

For the newspaper fraction emissions contributing to aquatic eutrophication (excluding NO_x) can be avoided through incineration. Recycling gives a net emission a little smaller than landfilling.

Regarding eutrophication (excluding NO_x) the ranking is the same for PET as for the whole system, but here the incineration alternative turns out avoiding emissions.

7.2.9 NO_x

For the whole system a net avoidance of NO_x emissions occur in the recycling alternatives. Landfill causes a net emission that is a bit lower than that caused by incineration.

For food waste net emissions of nitrogen oxides occur in all of the five treatment options. The smallest emission is made in the incineration case, followed by landfill, which emits a little bit less than digestion with heat and electricity production. Composting emits more and the largest emission is made when digesting and using the gas as bus fuel.

Recycling newspaper gives a net avoidance of NO_x emissions, since the virgin production uses more coal-based electricity. Landfilling results in a net emission of NO_x released in the surveyable time period. A larger net emission is made in the incineration alternative.

For PET net avoidance of NO_x emissions is made in the recycling and incineration alternatives, while landfill results in a net emission. The most NO_x is avoided in the recycling alternative.

7.2.10 SO_x

Net avoidance of SO_x emissions is made in the recycling and incineration options for all of the materials studied. Looking at the whole system the greatest amount of SO_x is avoided in the recycling alternatives. The major contribution to this comes from the avoidance of coal based electricity when replacing virgin newspaper. A little bit less emissions of SO_x are avoided when replacing biomass for heat production in the incineration case. Landfill result in net emissions of SO_x.

For food waste the best options for this category are digestion using the gas as bus fuel or composting for which the avoided emissions of SO_x are equal. Digestion and composting avoids SO_x emissions from production of phosphate fertiliser and for digestion also from diesel combustion. Not quite as much SO_x is avoided when using the digester gas for heat and electricity production or when incinerating. Landfilling gives rise to net emissions.

Newspaper and PET show the same pattern as the whole system.

7.2.11 Terrestrial eutrophication from NH_3

Looking at the whole system the largest amount of NH_3 is avoided through incineration. This avoidance is achieved since a larger amount of urea is used when burning forest residues compared to when incinerating waste. A smaller amount of NH_3 emissions are saved when recycling is combined with digestion, using the digester gas for electricity and heat production. Also in this case the saving comes from the avoided heat production from forest residues. Using the digester gas as bus fuel gives a net emission for the recycling alternative.

The net emission from landfilling is greater. The greatest net emission occurs when recycling is combined with composting of food waste.

The only option where a net emission of NH_3 is avoided for food waste is digestion, where the gas recovered is used for electricity and heat production. Using the digester gas as bus fuel gives a net emission mostly caused by transports of the food waste with truck. Incineration followed by landfill and then composting give rise to higher emissions of NH_3.

For newspaper the highest amount of NH_3 is avoided in the incineration alternative. Less is saved when landfilling whereas a net emission occurs in the recycling alternative.

For PET the situation is the same as for newspaper.

7.2.12 Toxicological effects

Ecotoxicity

Looking at the eco-toxicological effects gives a diverse and rather complicated picture. As an over all conclusion it can be noted that metals are the major contributors to this category. Only in a few cases VOC, in our calculations approximated as benzene, play a major role. For this impact category the weighting, which enables the aggregation across subcategories and the comparison between different characterisation methods, significantly influence the results. It should also be noted that the data on emissions of substances causing toxicological effects are often incomplete and that even when data are available characterisation and weighting factors are sometimes lacking. The results presented below are composed of emissions that we were able to quantify in this study.

The lowest weight to eco-toxicological effects is obtained using the EDIP method in combination with the weights chosen (see 6.3). For the whole system the most favourable option is incineration, where cadmium and zinc released in the surveyable time period can be avoided. These metals are part of the ashes brought back to the forest after burning forest residues for heat production. The second best alternative is recycling, where mainly VOC from the virgin production of PE are avoided. Landfill results in net emissions of eco-toxicants mainly due to releases of copper in the remaining time period.

Using the USES-LCA method and the minimum weights (USESmin), incineration is the preferable option for all materials except for newspaper. This is because zinc and chromium in the ashes from burning forest residues can be avoided. For the whole system landfill forms the second best alternative avoiding emissions of mercury from electricity production based on coal, and also zinc and chromium in the ashes from bio-fuelled heat production. For the recycling alternatives the avoided emissions of eco-toxic substances are a little bit less and it is mostly mercury from avoided electricity production. Emissions of heavy metals to soil from the digestion and composting residues worsen the total result for the recycling alternatives.

When using the USES-LCA method combined with the maximum weights (USESmax), recycling becomes the best alternative for all materials. This is due to that the effects in aquatic and sediment ecosystems have higher weights here, while the effects in terrestrial ecosystems have the same weight as in the minimum scenario. Avoiding the effects in aquatic and sediment ecosystems from the release of selenium and vanadium to air when producing coal based electricity accounts for the improvement of the recycling alternative. Incineration and landfill show similar results and for the whole system the net impact have an equal weight for both alternatives. Most of this weight comes, in both cases, from nickel and copper released to water in the remaining time period from ashes or waste landfilled.

Toxicological effects on human health

The EDIP method in combination with the weights used renders a weight of toxicological effects on human health that falls in-between those resulting from USES-LCA min and max. Looking at the whole system, the ranking is the same in all the three weighting combinations with recycling as the most favourable option followed by incineration and then last landfill.

With the EDIP method the avoided impact when recycling is mainly due to avoided releases of mercury when producing the electricity used in the avoided virgin production of newspaper and avoided VOC from virgin PE production. The weight of the avoided emissions from incineration is a bit less and consists mainly of arsenic, chromium and cadmium in the bio fuel ashes. Less still is the potential impact avoided in the landfill option, mainly consisting of mercury in the avoided electricity production based on coal.

With the USES-LCA method most of the avoided impact in the recycling alternatives is from VOC in the virgin production of PE. In the case of incineration the avoided impact is mostly from NMVOC emitted in heat production from bio fuel. Landfill results in a net impact mostly due to unspecified hydrocarbons from the compactors at the landfill site, in our calculations characterised as benzene.

Table 7.3 The table shows the weighted results for toxicological effects in SEK/year. The sub-categories have been weighted and added together into eco-toxicological effects (E-tox) and toxicological effects on human health (H-tox).

	Base scenario									
	Whole system	Food waste	Newspaper	Corrugated cardboard	Mixed cardboard	PE	PP	PS	PET	PVC
E-tox EDIP										
Rec dig h/e	-6.3E+06	2.0E+06	-1.9E+05	5.7E+05	-8.9E+05	-5.5E+06	-6.0E+05	-2.2E+05	-1.1E+06	-4.3E+05
Rec dig f	-5.4E+06	2.9E+06								
Rec comp	-8.0E+06	3.9E+05								
Incineration	-2.2E+07	-2.8E+06	-8.2E+06	-4.2E+06	-2.3E+06	-3.9E+06	-5.2E+05	-3.5E+05	-1.1E+05	-4.9E+04
Landfill	3.4E+05	-4.5E+05	4.6E+04	-8.0E+04	-4.9E+05	9.9E+05	1.3E+05	1.1E+05	5.4E+04	4.2E+04
E-tox USES min										
Rec dig h/e	-9.0E+07	1.2E+08	-1.7E+08	-2.8E+07	-9.7E+06	-1.2E+07	4.2E+06	3.4E+06	-7.3E+05	1.1E+06
Rec dig f	-4.3E+07	1.7E+08								
Rec comp	-5.4E+07	1.6E+08								
Incineration	-2.6E+08	-3.2E+07	-9.4E+07	-4.1E+07	-2.5E+07	-5.1E+07	-6.9E+06	-4.8E+06	-1.6E+06	-8.6E+05
Landfill	-1.0E+08	-3.1E+07	-3.6E+07	-2.2E+07	-1.2E+07	-3.2E+05	-6.7E+04	-2.6E+04	2.2E+04	2.2E+04
E-tox USES max										
Rec dig h/e	-1.2E+09	1.5E+09	-9.9E+08	-2.9E+08	-1.9E+09	1.0E+09	-1.3E+08	-2.2E+08	-1.2E+08	-3.8E+07
Rec dig f	-1.8E+09	1.9E+09								
Rec comp	-9.3E+08	1.8E+09								
Incineration	1.6E+10	2.2E+09	5.6E+09	1.8E+09	1.7E+09	3.3E+09	4.4E+08	3.5E+08	1.8E+08	1.4E+08
Landfill	1.6E+10	2.1E+09	5.7E+09	1.9E+09	1.8E+09	3.5E+09	4.7E+08	3.8E+08	1.9E+08	1.4E+08
H-tox EDIP										
Rec dig h/e	-7.5E+08	-1.3E+07	-2.4E+08	4.1E+06	-3.4E+07	-3.3E+08	-2.7E+07	7.3E+04	-8.4E+07	-1.2E+07
Rec dig f	-7.0E+08	3.2E+07								
Rec comp	-6.9E+08	3.9E+07								
Incineration	-3.1E+08	-3.5E+07	-1.1E+08	-4.9E+07	-2.9E+07	-6.4E+07	-8.8E+06	-5.8E+06	-1.8E+06	-7.9E+05
Landfill	-9.1E+07	-3.5E+07	-3.4E+07	-1.2E+07	-2.3E+07	9.4E+06	1.2E+06	1.0E+06	5.6E+05	4.4E+05
H-tox USES min										
Rec dig h/e	-2.0E+07	1.3E+06	-1.1E+06	1.0E+06	-1.2E+06	-1.3E+07	-1.2E+06	-3.4E+05	-3.5E+06	-1.1E+06
Rec dig f	-2.0E+07	9.6E+05								
Rec comp	-1.9E+07	1.7E+06								
Incineration	-3.9E+06	-3.6E+05	-1.4E+06	-6.6E+05	-3.6E+05	-9.1E+05	-1.2E+05	-8.4E+04	-2.8E+04	-1.4E+04
Landfill	6.6E+05	3.2E+04	3.1E+05	8.5E+04	6.9E+04	1.3E+05	1.7E+04	1.4E+04	7.1E+03	5.5E+03
H-tox USESmax										
Rec dig h/e	-4.4E+09	2.9E+08	-2.6E+08	2.3E+08	-2.7E+08	-3.0E+09	-2.7E+08	-7.8E+07	-8.0E+08	-2.5E+08
Rec dig f	-4.5E+09	2.2E+08								
Rec comp	-4.3E+09	3.9E+08								
Incineration	-8.9E+08	-8.2E+07	-3.1E+08	-1.5E+08	-8.2E+07	-2.1E+08	-2.8E+07	-1.9E+07	-6.3E+06	-3.2E+06
Landfill	1.5E+08	7.3E+06	6.9E+07	1.9E+07	1.6E+07	2.8E+07	3.8E+06	3.1E+06	1.6E+06	1.2E+06

7.2.13 Undefined substances

As discussed in section 2.3.8, the impact categories total energy, non-renewable energy, abiotic resources, global warming, SO_x and NO_x are reasonably well covered by the data and also by the characterisation and weighting. For the other impact categories the uncertainties are more significant, especially regarding toxicological effects. Extractions and emissions for which data is present in the inventory but that are not covered by the characterisation methods are shown in Appendix 3. Concerning the EDIP method it can be noted that for some subcategories we were unable to obtain weighting factors. These subcategories thus have a zero weight but this is not shown in the undefined substances record.

The list of undefined substances contains a number of substances of which a large part probably is of limited significance for the results and the conclusions but there may of course be a number of exceptions. One possible exception concerns emissions and waste from nuclear power which are not handled in the used impact assessment methods and there are probably also some datagaps in the inventory analysis. It may however be of interest to note that the different emissions of radioactive waste and substances that are inventoried and presented as undefined substances in Appendix 3 all give similar results. For the base scenario, the recycling strategies gives lower emissions and outflows of nuclear waste and emissions of radioactive substances to air and water. The results for landfilling and incineration are quite similar, although landfilling scores a little better.

Additives in plastics and paper materials are another group of substances for which there are large datagaps in the inventory analysis and often problems of handling them in the impact assessment. One example is DEHP which is used as an additive in PVC (see chapter 4). This substance is according to the modelling that is done here emitted in the landfilling base scenario but not in the recycling or incineration scenarios. In the incineration case, a best case assumption was made that DEHP will largely be destroyed in the incineration.

7.2.14 Total weighted results

The weighted impact categories are added together according to the combinations described in section 6.3, using Ecotax 98. The results are shown in Table 7.4. The ranking between the different treatment options is the same in all the weighting combinations when considering the whole system. Recycling gives the greatest net avoidance of environmental burden. A smaller avoidance is made in the incineration case when using the maximum weighting and the EDIP method for assessing toxicological effects, while incineration in the other two combinations and landfill show a net contribution to the environmental load.

In the Ecotax 98/EDIP combination abiotic resource use is the one impact category that influences the total result for the recycling alternatives the most, followed by toxicological effects on human health. In both cases there is a net avoidance of impact. For incineration there are several impact categories within the same range, influencing the total results. Avoided human toxicity is the largest, followed by a net contribution caused by greenhouse gases. Avoided contribution to photo–oxidant formation also plays a significant role. For landfill the total result is almost exclusively made up of the global warming impact category, but the photo-oxidant formation category is also visible.

When using the Ecotax 98/USESmin combination the main influence on the total result comes from the impact category global warming. In the recycling cases it is an avoided burden from this category, while for incineration and landfill it is a contribution. Terrestrial ecotoxicity also accounts for a major part of the total results for all treatment options.

In the Ecotax 98/USESmax combination the major contributor to the total result in the recycling cases is human toxicity, followed by abiotic resource use and eco-toxicity. Incineration is dominated by eco-toxicity, and even more so is landfill.

7.2.15 Eco-indicator 99

The total result from the impact assessment made with Eco-indicator 99 gives the same ranking as our own impact assessment method. The recycling alternatives have an avoided environmental burden, while incineration gives a net contribution smaller than in the landfilling alternative. For recycling the most influence on the result comes from the avoided use of fossil fuel resources. The avoided damage on human health caused by carcinogenic substances also plays a significant role, as do avoided respiratory effects caused by inorganic substances. For incineration the major contribution comes from damage to human health caused by carcinogenic substances, but the avoided burden from eco-toxicological effects is also visible in the total result. Effects on human health caused by carcinogenic substances is the main contributor to the total result for landfill, also influenced somewhat by damage on human health caused by climate change.

Table 7.4 The results for all impact categories weighted together. The Ecotax 98 method is applied in the combinations EDIP max, USES min and USES max as described in section 6.3. The results for these are shown in SEK/year. The results from using the Eco-indicator 99 method are shown in points.

	Base scenario									
	Whole system	Food waste	Newspaper	Corrugated cardboard	Mixed cardboard	PE	PP	PS	PET	PVC
Total Ecotax 98/EDIPmax										
Rec dig h/e	-3.4E+09	-2.4E+08	-1.6E+09	7.3E+07	-1.2E+08	-1.2E+09	-8.7E+07	-5.1E+07	-2.0E+08	-2.9E+07
Rec dig f	-3.4E+09	-1.7E+08								
Rec comp	-3.1E+09	1.6E+08								
Incineration	-9.4E+07	3.6E+07	-1.0E+08	-5.7E+07	3.7E+06	1.7E+07	1.9E+06	4.1E+06	2.2E+06	1.6E+06
Landfill	7.6E+08	1.5E+08	1.9E+08	1.2E+08	1.1E+08	1.5E+08	2.0E+07	1.6E+07	6.1E+06	3.4E+06
Total Ecotax 98/USESmin										
Rec dig h/e	-5.3E+08	6.8E+07	-4.9E+08	-3.5E+07	-1.7E+07	-5.0E+07	1.2E+07	8.2E+06	-2.5E+07	9.2E+05
Rec dig f	-4.4E+08	1.6E+08								
Rec comp	-4.2E+08	1.8E+08								
Incineration	6.7E+06	3.4E+07	-7.4E+07	-4.4E+07	9.8E+06	6.1E+07	7.9E+06	7.9E+06	3.0E+06	1.7E+06
Landfill	8.7E+08	2.1E+08	2.2E+08	1.4E+08	1.2E+08	1.3E+08	1.8E+07	1.5E+07	5.4E+06	2.8E+06
Total Ecotax 98/USESmax										
Rec dig h/e	-8.3E+09	1.5E+09	-2.6E+09	5.8E+06	-2.3E+09	-2.8E+09	-4.6E+08	-3.5E+08	-1.0E+09	-3.1E+08
Rec dig f	-8.1E+09	1.8E+09								
Rec comp	-7.6E+09	2.3E+09								
Incineration	1.5E+10	2.2E+09	5.3E+09	1.7E+09	1.7E+09	3.1E+09	4.2E+08	3.4E+08	1.8E+08	1.4E+08
Landfill	1.7E+10	2.3E+09	6.0E+09	2.0E+09	1.9E+09	3.7E+09	4.9E+08	3.9E+08	2.0E+08	1.5E+08
Total Eco-indicator 99										
Rec dig h/e	-5.3E+07	1.6E+07	-1.2E+07	-4.8E+06	-6.3E+06	-2.4E+07	-6.6E+06	-7.1E+06	-3.2E+06	-4.3E+06
Rec dig f	-5.3E+07	1.5E+07								
Rec comp	-4.8E+07	2.0E+07								
Incineration	6.0E+07	1.3E+07	1.8E+07	3.8E+06	1.5E+07	7.7E+06	1.0E+06	9.4E+05	5.5E+05	4.8E+05
Landfill	1.0E+08	1.8E+07	3.2E+07	1.2E+07	2.0E+07	1.6E+07	2.1E+06	1.7E+06	8.1E+05	6.0E+05

7.2.16 Summary

In Table 7.5 a summary of the rankings of the waste management options for the different impacts categories is presented. The rankings are for the whole system with the base scenario assumptions.

Table 7.5 The ranking of the waste management options for the whole system for each impact category. When the three recycling alternatives are ranked in a row they are presented as one, Rec. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling.

Impact category	**Ranking**						
Total energy	Rec	<	Inc	<	Lf		
Non-renewable energy	Rec	<	Lf	<	Inc		
Abiotic resources	Rec	<	Lf	<	Inc		
Non-treated waste	Rec	<	Lf	<	Inc		
Global warming	Rec	<	Inc	<	Lf		
Photo-oxidant formation max	Rec	<	Inc	<	Lf		
Acidification (excl. SO_x and NO_x)	Rec/d	<	Inc	<	Lf	<	Rec/c
Aquatic eutrophication (excl. NO_x)	Rec	<	Inc	<	Lf		
SO_x	Rec	<	Inc	<	Lf		
NO_x	Rec	<	Lf	<	Inc		
NH_3 max	Inc	<	Rec/d	<	Lf	<	Rec/c
E-tox EDIP	Inc	<	Rec	<	Lf		
E-tox USESmin	Inc	<	Lf	<	Rec		
E-tox USESmax	Rec	<	Inc/Lf				
H-tox EDIP	Rec	<	Inc	<	Lf		
H-tox USESmin	Rec	<	Inc	<	Lf		
H-tox USESmax	Rec	<	Inc	<	Lf		
Ecotax98 / EDIP	Rec	<	Inc	<	Lf		
Ecotax98 / USESmin	Rec	<	Inc	<	Lf		
Ecotax98 / USESmax	Rec	<	Inc	<	Lf		
Eco-indicator 99	Rec	<	Inc	<	Lf		

7.3 Results Scenario Medium transports

In this scenario the transport distances to the treatment plants are lengthened compared to the base scenario and also the transports of digestion and composting residues to fields. The added distances differ between treatment options, and for recycling also between waste materials. The effect of this is that impacts from transports with diesel truck, proportional to the appended distances, are added to the results from the base scenario. In general, it can be said that the least transport distance is added to landfill, followed by incineration and digestion and composting. The materials recycling options are charged with the longest additional distances. The assumptions regarding transport distances are described in section 3.4.

7.3.1 Energy, abiotic resources and non-treated waste

The longer transport distances have only a minor effect on the energy balances as well as the impact categories abiotic resources and non-treated waste. For food waste the ranking is however changed so that the net total energy savings are less when digesting and using the digester gas as bus fuel than in the landfill case. Incineration still has the largest net energy savings for food waste, followed by digestion where the recovered gas is used for heat and electricity production.

Table 7.6 Comparison between a scenario with medium transports and the base scenario. Total energy and non-renewable energy balances are shown in MJ/year. The impact categories abiotic resources and non-treated waste are weighted and the unit is SEK/year. Within these impact categories the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor

	Medium transports				**Base scenario**			
	Total	Food waste	Newspaper	PET	Total	Food waste	Newspaper	PET
Total energy								
Rec dig h/e	-3.7E+10	-1.6E+09	-2.2E+10	-4.4E+08	-3.8E+10	-2.2E+09	-2.2E+10	-4.4E+08
Rec dig f	-3.6E+10	-8.8E+08			-3.8E+10	-1.5E+09		
Rec comp	-3.4E+10	1.1E+09			-3.6E+10	4.3E+08		
Incineration	-2.0E+10	-2.0E+09	-7.3E+09	-1.4E+08	-2.2E+10	-2.7E+09	-7.9E+09	-1.4E+08
Landfill	-4.1E+09	-1.2E+09	-1.4E+09	3.3E+06	-5.2E+09	-1.2E+09	-1.8E+09	-8.5E+05
Non-renewable energy								
Rec dig h/e	-1.3E+10	-7.3E+08	-7.0E+09	-4.4E+08	-1.5E+10	-1.3E+09	-7.4E+09	-4.4E+08
Rec dig f	-1.4E+10	-8.7E+08			-1.5E+10	-1.5E+09		
Rec comp	-1.2E+10	1.1E+09			-1.3E+10	4.2E+08		
Incineration	2.4E+09	8.4E+08	8.4E+08	7.7E+06	4.8E+08	1.3E+08	2.4E+08	7.5E+05
Landfill	-1.7E+09	-4.6E+08	-6.4E+08	4.3E+06	-2.9E+09	-6.7E+08	-9.9E+08	1.8E+05
Abiotic resources								
Rec dig h/e	-1.9E+09	-1.0E+08	-9.8E+08	-6.1E+07	-2.1E+09	-1.9E+08	-1.0E+09	-6.2E+07
Rec dig f	-1.9E+09	-1.2E+08			-2.1E+09	-2.1E+08		
Rec comp	-1.7E+09	1.5E+08			-1.8E+09	5.9E+07		
Incineration	3.4E+08	1.2E+08	1.2E+08	1.1E+06	7.0E+07	1.8E+07	3.4E+07	1.2E+05
Landfill	-2.5E+08	-6.5E+07	-9.0E+07	5.9E+05	-4.0E+08	-1.2E+08	-1.4E+08	2.5E+04
Non-treated waste								
Rec dig h/e	-4.3E+07	-7.6E+06	-3.0E+07	-5.0E+06	-4.3E+07	-8.0E+06	-3.1E+07	-5.0E+06
Rec dig f	-3.5E+07	-6.9E+05			-3.6E+07	-1.1E+06		
Rec comp	-3.7E+07	-1.8E+06			-3.7E+07	-2.2E+06		
Incineration	5.9E+06	1.2E+06	2.3E+06	2.7E+04	4.7E+06	7.2E+05	2.0E+06	2.3E+04
Landfill	-1.4E+07	-4.2E+06	-5.0E+06	-3.2E+03	-1.5E+07	-4.5E+06	-5.2E+06	-5.9E+03

7.3.2 Non-toxicological impacts

The increased transport distances cause only a slight increase of CO_2 emissions compared to the base scenario and there are no changes in the rankings concerning the global warming impact category. The same is valid for the impact categories photo-oxidant formation, acidification (excl SO_x and NO_x), aquatic eutrophication (excl NO_x), and for SO_x and NH_3. For NO_x the ranking is altered for food waste in that the net emissions are smallest for landfill followed by digesting and using the gas for producing heat and electricity.

7.7 Comparison between a scenario with medium transports and the base scenario. The results are weighted and the unit is SEK/year. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	Medium transports				**Base scenario**			
	Total	Food waste	Newspaper	PET	Total	Food waste	Newspaper	PET
Global warming								
Rec dig (heat/el)	-2.0E+08	-3.0E+07	-2.0E+08	-4.5E+06	-2.4E+08	-4.6E+07	-2.2E+08	-4.6E+06
Rec dig (fuel)	-2.0E+08	-3.4E+07			-2.4E+08	-5.0E+07		
Rec comp	-1.5E+08	2.4E+07			-1.8E+08	7.2E+06		
Incineration	2.6E+08	2.8E+07	2.6E+07	5.1E+06	2.1E+08	8.8E+06	1.0E+07	4.9E+06
Landfill	8.8E+08	1.6E+08	2.6E+08	5.4E+06	8.5E+08	1.5E+08	2.5E+08	5.3E+06
Photo-oxidant formation max								
Rec dig h/e	-1.6E+08	3.7E+07	-4.9E+06	-3.6E+07	-2.0E+08	1.7E+07	-1.7E+07	-3.6E+07
Rec dig f	-1.6E+08	3.2E+07			-2.1E+08	1.2E+07		
Rec comp	-1.5E+08	4.4E+07			-1.9E+08	2.3E+07		
Incineration	-4.6E+07	1.1E+07	-2.0E+07	-5.1E+05	-1.1E+08	-1.2E+07	-3.9E+07	-7.3E+05
Landfill	3.5E+08	8.9E+07	1.3E+08	3.2E+05	3.2E+08	7.6E+07	1.2E+08	1.8E+05
Acidification (excl SO_x and NO_x)								
Rec dig h/e	-2.9E+06	-1.9E+05	-6.3E+05	-5.1E+05	-2.9E+06	-1.9E+05	-6.3E+05	-5.1E+05
Rec dig f	-2.7E+06	1.1E+04			-2.7E+06	5.4E+03		
Rec comp	1.4E+06	4.2E+06			1.4E+06	4.1E+06		
Incineration	-1.2E+06	9.0E+04	-5.2E+05	-9.5E+03	-1.2E+06	8.4E+04	-5.3E+05	-9.6E+03
Landfill	2.1E+05	4.7E+05	-1.6E+05	-1.6E+02	2.0E+05	4.7E+05	-1.6E+05	-2.0E+02
Aquatic eutrophication (excl NO_x)								
Rec dig h/e	-2.3E+06	-3.2E+06	3.4E+05	-1.5E+04	-2.3E+06	-3.2E+06	3.2E+05	-1.6E+04
Rec dig f	-2.2E+06	-3.2E+06			-2.3E+06	-3.2E+06		
Rec comp	2.0E+06	1.1E+06			1.9E+06	1.0E+06		
Incineration	6.5E+07	5.8E+07	-2.2E+04	-2.9E+03	6.5E+07	5.8E+07	-6.0E+04	-3.3E+03
Landfill	9.5E+07	8.6E+07	6.4E+05	1.6E+03	9.5E+07	8.6E+07	6.2E+05	1.4E+03
SO_x								
Rec dig h/e	-3.4E+07	3.7E+05	-1.1E+07	-2.1E+06	-3.5E+07	-3.5E+05	-1.1E+07	-2.1E+06
Rec dig f	-3.5E+07	-1.0E+06			-3.7E+07	-1.8E+06		
Rec comp	-3.5E+07	-9.9E+05			-3.7E+07	-1.8E+06		
Incineration	-7.9E+06	6.2E+05	-3.4E+06	-7.1E+04	-1.0E+07	-2.3E+05	-4.2E+06	-8.0E+04
Landfill	3.6E+06	1.3E+06	1.1E+06	7.3E+03	2.2E+06	8.1E+05	6.3E+05	2.8E+03
NO_x								
Rec dig h/e	-4.6E+07	1.9E+07	-5.5E+07	-4.2E+06	-8.3E+07	2.3E+06	-6.5E+07	-4.4E+06
Rec dig f	-3.0E+06	6.1E+07			-4.1E+07	4.5E+07		
Rec comp	-3.4E+07	3.1E+07			-7.2E+07	1.4E+07		
Incineration	6.2E+07	2.0E+07	3.4E+07	9.8E+04	9.4E+06	2.2E+05	1.7E+07	-9.0E+04
Landfill	3.7E+07	1.2E+07	1.2E+07	1.5E+05	6.5E+06	1.2E+06	2.6E+06	4.4E+04
NH_3 max								
Rec dig h/e	-1.4E+05	-2.1E+05	2.6E+05	3.4E+02	-1.6E+05	-2.2E+05	2.6E+05	2.2E+02
Rec dig f	8.6E+04	1.5E+04			5.8E+04	2.7E+03	2.6E+05	2.2E+02
Rec comp	1.6E+07	1.6E+07			1.6E+07	1.6E+07		
Incineration	-4.8E+06	2.7E+05	-2.2E+06	-3.8E+04	-4.8E+06	2.6E+05	-2.2E+06	-3.8E+04
Landfill	1.9E+06	2.1E+06	-2.1E+05	-1.6E+02	1.9E+06	2.1E+06	-2.1E+05	-2.4E+02

7.3.3 Toxicological effects

Medium transports have a minor effect on the impact category eco-toxicological effects, and the rankings between the different treatment options remain the same as in the base scenario.

Regarding toxicological effects on human health the lengthened transports are more visible in the results, especially for food waste and newspaper. For food waste landfill becomes the better option followed by incineration in all of the three methods EDIP, USES min, and USES max. Incineration of food waste goes from having a net avoided burden in the base scenario to having a net contribution in this scenario. For newspaper recycling becomes the preferable alternative also when using USES min and USES max in this scenario, followed by incineration, which goes from avoided impact to contributing to impact. The ranking for PET and the whole system stays the same as in the base scenario.

7.8 Comparison between a scenario with medium transports and the base scenario. The table shows the weighted results for toxicological effects in SEK/year. The sub-categories have been weighted and added together into eco-toxicological effects (E-tox) and toxicological effects on human health (H-tox).

	Medium transports				**Base scenario**			
	Total	Food waste	Newspaper	PET	Total	Food waste	Newspaper	PET
E-tox EDIP								
Rec dig h/e	-4.9E+06	2.6E+06	1.9E+05	-1.1E+06	-6.3E+06	2.0E+06	-1.9E+05	-1.1E+06
Rec dig f	-4.1E+06	3.5E+06			-5.4E+06	2.9E+06		
Rec comp	-6.6E+06	1.0E+06			-8.0E+06	3.9E+05		
Incineration	-2.1E+07	-2.1E+06	-7.6E+06	-1.0E+05	-2.2E+07	-2.8E+06	-8.2E+06	-1.1E+05
Landfill	1.5E+06	-4.2E+04	4.0E+05	5.8E+04	3.4E+05	-4.5E+05	4.6E+04	5.4E+04
E-tox USES min								
Rec dig h/e	-8.9E+07	1.2E+08	-1.7E+08	-7.2E+05	-9.0E+07	1.2E+08	-1.7E+08	-7.3E+05
Rec dig f	-4.2E+07	1.7E+08			-4.3E+07	1.7E+08		
Rec comp	-5.3E+07	1.6E+08			-5.4E+07	1.6E+08		
Incineration	-2.6E+08	-3.2E+07	-9.4E+07	-1.6E+06	-2.6E+08	-3.2E+07	-9.4E+07	-1.6E+06
Landfill	-1.0E+08	-3.1E+07	-3.6E+07	2.5E+04	-1.0E+08	-3.1E+07	-3.6E+07	2.2E+04
E-tox USES max								
Rec dig h/e	-1.0E+09	1.6E+09	-9.4E+08	-1.2E+08	-1.2E+09	1.5E+09	-9.9E+08	-1.2E+08
Rec dig f	-7.7E+08	1.8E+09			-1.9E+09	1.8E+09		
Rec comp	-7.6E+08	1.8E+09			-9.3E+08	1.8E+09		
Incineration	1.6E+10	2.3E+09	5.7E+09	1.8E+08	1.6E+10	2.2E+09	5.6E+09	1.8E+08
Landfill	1.6E+10	2.2E+09	5.8E+09	1.9E+08	1.6E+10	2.1E+09	5.7E+09	1.9E+08
H-tox EDIP								
Rec dig h/e	-6.4E+08	3.2E+07	-2.2E+08	-8.4E+07	-7.5E+08	-1.3E+07	-2.4E+08	-8.4E+07
Rec dig f	-6.0E+08	7.7E+07			-7.0E+08	3.2E+07		
Rec comp	-5.9E+08	8.6E+07			-6.9E+08	3.9E+07		
Incineration	-1.6E+08	1.8E+07	-6.8E+07	-1.3E+06	-3.1E+08	-3.5E+07	-1.1E+08	-1.8E+06
Landfill	-7.7E+06	-4.6E+06	-7.6E+06	8.6E+05	-9.1E+07	-3.5E+07	-3.4E+07	5.6E+05
H-tox USES min								
Rec dig h/e	-1.6E+07	3.0E+06	-5.3E+04	-3.5E+06	-2.0E+07	1.3E+06	-1.1E+06	-3.5E+06
Rec dig f	-1.6E+07	2.7E+06			-2.0E+07	9.6E+05		
Rec comp	-1.5E+07	3.5E+06			-1.9E+07	1.7E+06		
Incineration	1.6E+06	1.7E+06	3.3E+05	-8.3E+03	-3.9E+06	-3.6E+05	-1.4E+06	-2.8E+04
Landfill	3.9E+06	1.2E+06	1.3E+06	1.9E+04	6.6E+05	3.2E+04	3.1E+05	7.1E+03
H-tox USESmax								
Rec dig h/e	-3.5E+09	6.8E+08	-1.2E+07	-8.0E+08	-4.4E+09	2.9E+08	-2.6E+08	-8.0E+08
Rec dig f	-3.6E+09	6.1E+08			-4.5E+09	2.2E+08		
Rec comp	-3.4E+09	8.0E+08			-4.3E+09	3.9E+08		
Incineration	3.5E+08	3.8E+08	7.5E+07	-1.9E+06	-8.9E+08	-8.2E+07	-3.1E+08	-6.3E+06
Landfill	8.8E+08	2.7E+08	3.0E+08	4.2E+06	1.5E+08	7.3E+06	6.9E+07	1.6E+06

7.3.4 Total weighted results

The increased transport distances do not affect the total weighted results very much. Compared to the base scenario the ranking changes only for food waste in the USES max combination so that landfill becomes slightly better than incineration and composting which both have equal weights. Recycling combined with digestion is still the best alternative for food waste.

7.9 Comparison between a scenario with medium transports and the base scenario. The results for all impact categories weighted together. The Ecotax 98 method is applied in the combinations EDIP max, USES min and USES max as described in section 6.3. The results for these are shown in SEK/year. The results from using the Eco-indicator 99 method are shown in points.

	Medium transports				**Base scenario**			
	Total	Food waste	Newspaper	PET	Total	Food waste	Newspaper	PET
Total Ecotax 98/ EDIPmax								
Rec dig h/e	-3.0E+09	-5.5E+07	-1.5E+09	-2.0E+08	-3.4E+09	-2.4E+08	-1.6E+09	-2.0E+08
Rec dig f	-3.0E+09	1.1E+07			-3.4E+09	-1.7E+08		
Rec comp	-2.6E+09	3.5E+08			-3.1E+09	1.6E+08		
Incineration	4.9E+08	2.5E+08	7.8E+07	4.3E+06	-9.4E+07	3.6E+07	-1.0E+08	2.2E+06
Landfill	1.0E+09	2.8E+08	3.0E+08	7.4E+06	7.6E+08	1.5E+08	1.9E+08	6.1E+06
Total Ecotax 98/ USESmin								
Rec dig h/e	-4.5E+08	1.1E+08	-4.7E+08	-2.4E+07	-5.3E+08	6.8E+07	-4.9E+08	-2.5E+07
Rec dig f	-3.6E+08	2.0E+08			-4.4E+08	1.6E+08		
Rec comp	-3.3E+08	2.2E+08			-4.2E+08	1.8E+08		
Incineration	1.3E+08	7.9E+07	-3.6E+07	3.5E+06	6.7E+06	3.4E+07	-7.4E+07	3.0E+06
Landfill	9.4E+08	2.3E+08	2.4E+08	5.6E+06	8.7E+08	2.1E+08	2.2E+08	5.4E+06
Total Ecotax 98/ USESmax								
Rec dig h/e	-7.0E+09	2.1E+09	-2.2E+09	-1.0E+09	-8.3E+09	1.5E+09	-2.6E+09	-1.0E+09
Rec dig f	-6.7E+09	2.4E+09			-8.1E+09	1.8E+09		
Rec comp	-6.2E+09	2.9E+09			-7.6E+09	2.3E+09		
Incineration	1.7E+10	2.9E+09	5.9E+09	1.9E+08	1.5E+10	2.2E+09	5.3E+09	1.8E+08
Landfill	1.8E+10	2.7E+09	6.4E+09	2.0E+08	1.7E+10	2.3E+09	6.0E+09	2.0E+08
Eco-indicator 99								
Rec dig h/e	-4.4E+07	1.9E+07	-9.4E+06	-3.2E+06	-5.3E+07	1.6E+07	-1.2E+07	-3.2E+06
Rec dig f	-4.5E+07	1.8E+07			-5.3E+07	1.5E+07		
Rec comp	-4.0E+07	2.4E+07			-4.8E+07	2.0E+07		
Incineration	7.2E+07	1.7E+07	2.1E+07	5.9E+05	6.0E+07	1.3E+07	1.8E+07	5.5E+05
Landfill	1.1E+08	2.1E+07	3.4E+07	8.4E+05	1.0E+08	1.8E+07	3.2E+07	8.1E+05

7.3.5 Summary

A final summary of the ranking of the waste management options in the scenario with medium transports, for the whole system, is given in Table 7.10.

Table 7.10 The ranking of the waste management options for the whole system for each impact category. When the three recycling alternatives are ranked in sequence they are reported as one. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling.

Impact category	Ranking						
Total energy	Rec	<	Inc	<	Lf		
Non-renewable energy	Rec	<	Lf	<	Inc		
Abiotic resources	Rec	<	Lf	<	Inc		
Non-treated waste	Rec	<	Lf	<	Inc		
Global warming	Rec	<	Inc	<	Lf		
Photo-oxidant formation max	Rec	<	Inc	<	Lf		
Acidification (excl. SO_x and NO_x)	Rec/d	<	Inc	<	Lf	<	Rec/c
Aquatic eutrophication (excl. NO_x)	Rec	<	Inc	<	Lf		
SO_x	Rec	<	Inc	<	Lf		
NO_x	Rec	<	Lf	<	Inc		
NH_3 max	Inc	<	Rec/d	<	Lf	<	Rec/c
E- tox EDIP	Inc	<	Rec	<	Lf		
E- tox USESmin	Inc	<	Lf	<	Rec		
E- tox USESmax	Rec	<	Inc=Lf				
H- tox EDIP	Rec	<	Inc	<	Lf		
H- tox USESmin	Rec	<	Inc	<	Lf		
H- tox USESmax	Rec	<	Inc	<	Lf		
Ecotax98 / EDIP	Rec	<	Inc	<	Lf		
Ecotax98 / USESmin	Rec	<	Inc	<	Lf		
Ecotax98 / USESmax	Rec	<	Inc	<	Lf		
Eco-indicator 99	Rec	<	Inc	<	Lf		

7.4 Results Scenario Long transports

In this scenario the transport distances are further increased, mainly for transports of waste from reloading point to recycling facilities. The assumptions regarding transport distances are described in section 3.4. This scenario will give an indication of if longer transports by truck in the recycling cases will lead to significant environmental draw-backs for this waste treatment strategy.

7.4.1 Energy, abiotic resources and non-treated waste

Compared to the scenario with medium transports changes in the categories total and non-renewable energy, abiotic resources and non-treated waste are small. The one difference in ranking compared to the base scenario stays the same.

Table 7.11 Comparison between a scenario with long transports and the base scenario. Total energy and non-renewable energy balances are shown in MJ/year. The impact categories abiotic resources and non-treated waste are weighted and the unit is SEK/year. Within these impact categories the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor

	Long transports				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Total energy								
Rec dig h/e	-3,6E+10	-1,5E+09	-2,1E+10	-4,2E+08	-3.8E+10	-2.2E+09	-2.2E+10	-4.4E+08
Rec dig f	-3,6E+10	-8,6E+08			-3.8E+10	-1.5E+09		
Rec comp	-3,4E+10	1,1E+09			-3.6E+10	4.3E+08		
Incineration	-2,0E+10	-2,0E+09	-7,3E+09	-1,4E+08	-2.2E+10	-2.7E+09	-7.9E+09	-1.4E+08
Landfill	-4,1E+09	-1,2E+09	-1,4E+09	3,3E+06	-5.2E+09	-1.2E+09	-1.8E+09	-8.5E+05
Non-renewable energy								
Rec dig h/e	-1,3E+10	-7,1E+08	-6,8E+09	-4,2E+08	-1.5E+10	-1.3E+09	-7.4E+09	-4.4E+08
Rec dig f	-1,3E+10	-8,5E+08			-1.5E+10	-1.5E+09		
Rec comp	-1,1E+10	1,1E+09			-1.3E+10	4.2E+08		
Incineration	2,4E+09	8,4E+08	8,4E+08	7,7E+06	4.8E+08	1.3E+08	2.4E+08	7.5E+05
Landfill	-1,7E+09	-4,6E+08	-6,4E+08	4,3E+06	-2.9E+09	-6.7E+08	-9.9E+08	1.8E+05
Abiotic resources								
Rec dig h/e	-1,8E+09	-1,0E+08	-9,5E+08	-5,9E+07	-2.1E+09	-1.9E+08	-1.0E+09	-6.2E+07
Rec dig f	-1,8E+09	-1,2E+08			-2.1E+09	-2.1E+08		
Rec comp	-1,6E+09	1,5E+08			-1.8E+09	5.9E+07		
Incineration	3,4E+08	1,2E+08	1,2E+08	1,1E+06	7.0E+07	1.8E+07	3.4E+07	1.2E+05
Landfill	-2,5E+08	-6,5E+07	-9,0E+07	5,9E+05	-4.0E+08	-1.2E+08	-1.4E+08	2.5E+04
Non-treated waste								
Rec dig h/e	-4,2E+07	-7,6E+06	-3,0E+07	-5,0E+06	-4.3E+07	-8.0E+06	-3.1E+07	-5.0E+06
Rec dig f	-3,5E+07	-6,7E+05			-3.6E+07	-1.1E+06		
Rec comp	-3,6E+07	-1,8E+06			-3.7E+07	-2.2E+06		
Incineration	5,9E+06	1,2E+06	2,3E+06	2,7E+04	4.7E+06	7.2E+05	2.0E+06	2.3E+04
Landfill	-1,4E+07	-4,2E+06	-5,0E+06	-3,2E+03	-1.5E+07	-4.5E+06	-5.2E+06	-5.9E+03

7.4.2 Non-toxicological impacts

For the global warming category the longer transport distances for the recycling option only have little impact and the rankings stays the same as in the base and medium transport scenarios. This means for the fractions presented here and for the whole system, that recycling is preferable to incineration, which is preferable to landfill. For the other non-toxicological impact categories, the differences compared to the medium transport scenario are mostly minor and no change in rankings compared to this scenario is seen.

7.12 Comparison between a scenario with long transports and the base scenario. The results are weighted and the unit is SEK/year. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	Long transports				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Global warming								
Rec dig (heat/el)	-1,8E+08	-2,9E+07	-2,0E+08	-4,1E+06	-2.4E+08	-4.6E+07	-2.2E+08	-4.6E+06
Rec dig (fuel)	-1,9E+08	-3,3E+07			-2.4E+08	-5.0E+07		
Rec comp	-1,3E+08	2,5E+07			-1.8E+08	7.2E+06		
Incineration	2,6E+08	2,8E+07	2,6E+07	5,1E+06	2.1E+08	8.8E+06	1.0E+07	4.9E+06
Landfill	8,8E+08	1,6E+08	2,6E+08	5,4E+06	8.5E+08	1.5E+08	2.5E+08	5.3E+06
Photo-oxidant formation max								
Rec dig h/e	-1,4E+08	3,7E+07	1,7E+06	-3,5E+07	-2.0E+08	1.7E+07	-1.7E+07	-3.6E+07
Rec dig f	-1,4E+08	3,2E+07			-2.1E+08	1.2E+07		
Rec comp	-1,3E+08	4,4E+07			-1.9E+08	2.3E+07		
Incineration	-4,6E+07	1,1E+07	-2,0E+07	-5,1E+05	-1.1E+08	-1.2E+07	-3.9E+07	-7.3E+05
Landfill	3,5E+08	8,9E+07	1,3E+08	3,2E+05	3.2E+08	7.6E+07	1.2E+08	1.8E+05
Acidification (excl SO_x and NO_x)								
Rec dig h/e	-2,9E+06	-1,9E+05	-6,3E+05	-5,1E+05	-2.9E+06	-1.9E+05	-6.3E+05	-5.1E+05
Rec dig f	-2,7E+06	1,1E+04			-2.7E+06	5.4E+03		
Rec comp	1,5E+06	4,2E+06			1.4E+06	4.1E+06		
Incineration	-1,2E+06	9,0E+04	-5,2E+05	-9,5E+03	-1.2E+06	8.4E+04	-5.3E+05	-9.6E+03
Landfill	2,1E+05	4,7E+05	-1,6E+05	-1,6E+02	2.0E+05	4.7E+05	-1.6E+05	-2.0E+02
Aquatic eutrophication (excl NO_x)								
Rec dig h/e	-2,2E+06	-3,2E+06	3,5E+05	-1,5E+04	-2.3E+06	-3.2E+06	3.2E+05	-1.6E+04
Rec dig f	-2,2E+06	-3,2E+06			-2.3E+06	-3.2E+06		
Rec comp	2,0E+06	1,1E+06			1.9E+06	1.0E+06		
Incineration	6,5E+07	5,8E+07	-2,2E+04	-2,9E+03	6.5E+07	5.8E+07	-6.0E+04	-3.3E+03
Landfill	9,5E+07	8,6E+07	6,4E+05	1,6E+03	9.5E+07	8.6E+07	6.2E+05	1.4E+03
SO_x								
Rec dig h/e	-3,3E+07	4,0E+05	-1,1E+07	-2,1E+06	-3.5E+07	-3.5E+05	-1.1E+07	-2.1E+06
Rec dig f	-3,4E+07	-1,0E+06			-3.7E+07	-1.8E+06		
Rec comp	-3,4E+07	-9,7E+05			-3.7E+07	-1.8E+06		
Incineration	-7,9E+06	6,3E+05	-3,4E+06	-7,1E+04	-1.0E+07	-2.3E+05	-4.2E+06	-8.0E+04
Landfill	3,6E+06	1,3E+06	1,1E+06	7,6E+03	2.2E+06	8.1E+05	6.3E+05	2.8E+03
NO_x								
Rec dig h/e	-3,0E+07	1,9E+07	-4,9E+07	-3,9E+06	-8.3E+07	2.3E+06	-6.5E+07	-4.4E+06
Rec dig f	1,3E+07	6,2E+07			-4.1E+07	4.5E+07		
Rec comp	-1,8E+07	3,1E+07			-7.2E+07	1.4E+07		
Incineration	6,2E+07	2,0E+07	3,4E+07	9,8E+04	9.4E+06	2.2E+05	1.7E+07	-9.0E+04
Landfill	3,7E+07	1,2E+07	1,2E+07	1,5E+05	6.5E+06	1.2E+06	2.6E+06	4.4E+04
NH_3 max								
Rec dig h/e	-1,2E+05	-2,1E+05	2,7E+05	6,1E+02	-1.6E+05	-2.2E+05	2.6E+05	2.2E+02
Rec dig f	9,9E+04	1,5E+04			5.8E+04	2.7E+03	2.6E+05	2.2E+02
Rec comp	1,6E+07	1,6E+07			1.6E+07	1.6E+07		
Incineration	-4,8E+06	2,7E+05	-2,2E+06	-3,8E+04	-4.8E+06	2.6E+05	-2.2E+06	-3.8E+04
Landfill	1,9E+06	2,1E+06	-2,1E+05	-1,6E+02	1.9E+06	2.1E+06	-2.1E+05	-2.4E+02

7.4.3 Toxicological effects

The effects of longer transports in the recycling cases result in altered rankings compared to the base and medium transports scenario for some toxicological assessments. For eco-toxicological effects using the EDIP method this is the case for the newspaper fraction, where the increased transport distances leads to a fall in preference from second to third for recycling. This is mainly due to emissions of NMVOC from the trucks, which is considered as benzene in the assessment of toxicological effects. However this change is not seen using the USES methods

The same emission leads to changes in the rankings of treatment of the newspaper fraction also when considering human toxicological impacts. When using the USES-method for characterisation, both with maximum and minimum weight, recycling falls from first to second in ranking compared to the base and medium transport scenarios, leaving incineration as highest ranked.

7.13 Comparison between a scenario with long transports and the base scenario. The table shows the weighted results for toxicological effects in SEK/year. The sub-categories have been weighted and added together into eco-toxicological effects (E-tox) and toxicological effects on human health (H-tox).

	Long transports				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
E-tox EDIP								
Rec dig h/e	-4,2E+06	2,7E+06	4,1E+05	-9,9E+05	-6.3E+06	2.0E+06	-1.9E+05	-1.1E+06
Rec dig f	-3,4E+06	3,5E+06			-5.4E+06	2.9E+06		
Rec comp	-5,9E+06	1,0E+06			-8.0E+06	3.9E+05		
Incineration	-2,1E+07	-2,1E+06	-7,6E+06	-1,0E+05	-2.2E+07	-2.8E+06	-8.2E+06	-1.1E+05
Landfill	1,5E+06	-4,2E+04	4,0E+05	5,8E+04	3.4E+05	-4.5E+05	4.6E+04	5.4E+04
E-tox USES min								
Rec dig h/e	-8,8E+07	1,2E+08	-1,7E+08	-7,1E+05	-9.0E+07	1.2E+08	-1.7E+08	-7.3E+05
Rec dig f	-4,2E+07	1,7E+08			-4.3E+07	1.7E+08		
Rec comp	-5,2E+07	1,6E+08			-5.4E+07	1.6E+08		
Incineration	-2,6E+08	-3,2E+07	-9,4E+07	-1,6E+06	-2.6E+08	-3.2E+07	-9.4E+07	-1.6E+06
Landfill	-1,0E+08	-3,1E+07	-3,6E+07	2,5E+04	-1.0E+08	-3.1E+07	-3.6E+07	2.2E+04
E-tox USES max								
Rec dig h/e	-9,7E+08	1,6E+09	-9,2E+08	-1,1E+08	-1.2E+09	1.5E+09	-9.9E+08	-1.2E+08
Rec dig f	-7,0E+08	1,8E+09			-1.9E+09	1.8E+09		
Rec comp	-6,9E+08	1,8E+09			-9.3E+08	1.8E+09		
Incineration	1,6E+10	2,3E+09	5,7E+09	1,8E+08	1.6E+10	2.2E+09	5.6E+09	1.8E+08
Landfill	1,6E+10	2,2E+09	5,8E+09	1,9E+08	1.6E+10	2.1E+09	5.7E+09	1.9E+08
H-tox EDIP								
Rec dig h/e	-6,0E+08	3,3E+07	-2,0E+08	-8,3E+07	-7.5E+08	-1.3E+07	-2.4E+08	-8.4E+07
Rec dig f	-5,5E+08	7,9E+07			-7.0E+08	3.2E+07		
Rec comp	-5,5E+08	8,6E+07			-6.9E+08	3.9E+07		
Incineration	-1,6E+08	1,8E+07	-6,7E+07	-1,3E+06	-3.1E+08	-3.5E+07	-1.1E+08	-1.8E+06
Landfill	-7,7E+06	-4,6E+06	-7,6E+06	8,6E+05	-9.1E+07	-3.5E+07	-3.4E+07	5.6E+05
H-tox USES min								
Rec dig h/e	-1,4E+07	3,0E+06	5,4E+05	-3,5E+06	-2.0E+07	1.3E+06	-1.1E+06	-3.5E+06
Rec dig f	-1,4E+07	2,7E+06			-2.0E+07	9.6E+05		
Rec comp	-1,4E+07	3,5E+06			-1.9E+07	1.7E+06		
Incineration	1,6E+06	1,7E+06	3,3E+05	-8,3E+03	-3.9E+06	-3.6E+05	-1.4E+06	-2.8E+04
Landfill	3,9E+06	1,2E+06	1,3E+06	1,9E+04	6.6E+05	3.2E+04	3.1E+05	7.1E+03
H-tox USESmax								
Rec dig h/e	-3,2E+09	6,9E+08	1,2E+08	-7,9E+08	-4.4E+09	2.9E+08	-2.6E+08	-8.0E+08
Rec dig f	-3,2E+09	6,2E+08			-4.5E+09	2.2E+08		
Rec comp	-3,1E+09	8,0E+08			-4.3E+09	3.9E+08		
Incineration	3,6E+08	3,8E+08	7,6E+07	-1,9E+06	-8.9E+08	-8.2E+07	-3.1E+08	-6.3E+06
Landfill	8,8E+08	2,7E+08	3,0E+08	4,2E+06	1.5E+08	7.3E+06	6.9E+07	1.6E+06

7.4.4 Total weighted results

Changes in the total weighted results, comparing the long transport scenario to the medium transport scenario, are relatively small and do not change the rankings of the treatment options.

7.14 Comparison between a scenario with long transports and the base scenario. The results for all impact categories weighted together. The Ecotax 98 method is applied in the combinations EDIP max, USES min and USES max as described in section 6.3. The results for these are shown in SEK/year. The results from using the Eco-indicator 99 method are shown in points.

	Long transports				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Total Ecotax 98/ EDIPmax								
Rec dig h/e	-2,9E+09	-4,9E+07	-1,4E+09	-2.0E+08	-3.4E+09	-1,9E+08	-1.6E+09	-2.0E+08
Rec dig f	-2,8E+09	1,7E+07			-3.4E+09			
Rec comp	-2,5E+09	3,5E+08			-3.1E+09			
Incineration	4,9E+08	2,5E+08	7,9E+07	4.3E+06	-9.4E+07	4,3E+06	-1.0E+08	2.2E+06
Landfill	1,0E+09	2,8E+08	3,0E+08	7.4E+06	7.6E+08	7,4E+06	1.9E+08	6.1E+06
Total Ecotax 98/ USESmin								
Rec dig h/e	-4,1E+08	1,1E+08	-4,6E+08	-2.4E+07	-5.3E+08	-2,3E+07	-4.9E+08	-2.5E+07
Rec dig f	-3,2E+08	2,0E+08			-4.4E+08			
Rec comp	-3,0E+08	2,2E+08			-4.2E+08			
Incineration	1,3E+08	7,9E+07	-3,6E+07	3.5E+06	6.7E+06	3,5E+06	-7.4E+07	3.0E+06
Landfill	9,4E+08	2,3E+08	2,4E+08	5.6E+06	8.7E+08	5,6E+06	2.2E+08	5.4E+06
Total Ecotax 98/ USESmax								
Rec dig h/e	-6,4E+09	2,2E+09	-2,0E+09	-1.0E+09	-8.3E+09	-1,0E+09	-2.6E+09	-1.0E+09
Rec dig f	-6,2E+09	2,4E+09			-8.1E+09			
Rec comp	-5,7E+09	2,9E+09			-7.6E+09			
Incineration	1,7E+10	2,9E+09	5,9E+09	1.9E+08	1.5E+10	1,9E+08	5.3E+09	1.8E+08
Landfill	1,8E+10	2,7E+09	6,4E+09	2.0E+08	1.7E+10	2,0E+08	6.0E+09	2.0E+08
Eco-indicator 99								
Rec dig h/e	-4,1E+07	1,9E+07	-8,1E+06	-3.2E+06	-5.3E+07	-3,1E+06	-1.2E+07	-3.2E+06
Rec dig f	-4,2E+07	1,9E+07			-5.3E+07			
Rec comp	-3,7E+07	2,4E+07			-4.8E+07			
Incineration	7,2E+07	1,7E+07	2,1E+07	5.9E+05	6.0E+07	5,9E+05	1.8E+07	5.5E+05
Landfill	1,1E+08	2,1E+07	3,4E+07	8.4E+05	1.0E+08	8,4E+05	3.2E+07	8.1E+05

7.4.5 Summary

A final summary of the ranking of the waste management options in the scenario with long transports, for the whole system, is given in Table 7.15. The rankings are the same as in the medium transport scenario.

Table 7.15 The ranking of the waste management options for the whole system for each impact category. When the three recycling alternatives are ranked in sequence they are reported as one. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling.

Impact category	**Ranking**						
Total energy	Rec	<	Inc	<	Lf		
Non-renewable energy	Rec	<	Lf	<	Inc		
Abiotic resources	Rec	<	Lf	<	Inc		
Non-treated waste	Rec	<	Lf	<	Inc		
Global warming	Rec	<	Inc	<	Lf		
Photo-oxidant formation max	Rec	<	Inc	<	Lf		
Acidification (excl. SO_x and NO_x)	Rec/d	<	Inc	<	Lf	<	Rec/c
Aquatic eutrophication (excl. NO_x)	Rec	<	Inc	<	Lf		
SO_x	Rec	<	Inc	<	Lf		
NO_x	Rec	<	Lf	<	Inc		
NH_3 max	Inc	<	Rec/d	<	Lf	<	Rec/c
E- tox EDIP	Inc	<	Rec	<	Lf		
E- tox USESmin	Inc	<	Lf	<	Rec		
E- tox USESmax	Rec	<	Inc=Lf				
H- tox EDIP	Rec	<	Inc	<	Lf		
H- tox USESmin	Rec	<	Inc	<	Lf		
H- tox USESmax	Rec	<	Inc	<	Lf		
Ecotax98 / EDIP	Rec	<	Inc	<	Lf		
Ecotax98 / USESmin	Rec	<	Inc	<	Lf		
Ecotax98 / USESmax	Rec	<	Inc	<	Lf		
Eco-indicator 99	Rec	<	Inc	<	Lf		

7.5 Results Scenario Medium transports and transports by passenger car

In this scenario the same extended distances as applied in the scenario with medium transports are used. In addition, 1 km extra transport with passenger car is assumed per kg waste treated with recycling, digestion, composting and incineration. For incineration an alternative where no transport is performed by passenger car is also compared with the other treatments to see how this affects the rankings. In the landfill alternative no car transports are assumed.

7.5.1 Energy, abiotic resources and non-treated waste

Medium transports and transportation carried out with passenger car does not influence the results much for the energy balances, abiotic resources and untreated waste, other than for food waste (see Table 7.16).

For the food waste fraction the ranking for the total energy balance is changed. Incineration is still the most energy saving, but now followed by landfill. Digestion and composting cause a net expenditure of energy. Looking at the non-renewable energy, landfill is the only option for food waste where net savings are made in this scenario. Digestion where the recovered gas is used as bus fuel has the lowest net expenditure of non-renewable energy followed by incineration, if no passenger car trips are included. If they are, digestion where the gas is used for heat and electricity production is better than incineration which in turn is better than composting the food waste. Net savings of abiotic resources are made when the food waste is landfilled. Digestion causes a net use, a little less than incineration. More abiotic resources still are used when composting.

Table 7.16 Comparison between a scenario with medium transports and the base scenario. The added transport distances are the same as in section 7.3 but for recycling, digestion, composting and incineration extra car transport of 1 km/kg treated waste is also added. For incineration the alternative where no car transports are made is also shown. Total energy and non-renewable energy balances are shown in MJ/year. The impact categories resources and non-treated waste are weighted and the unit is SEK/year. Within these impact categories the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	Medium transports + passenger car				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Total energy								
Rec dig h/e	-3.2E+10	5.6E+07	-2.0E+10	-4.2E+08	-3.8E+10	-2.2E+09	-2.2E+10	-4.4E+08
Rec dig f	-3.1E+10	7.4E+08			-3.8E+10	-1.5E+09		
Rec comp	-2.9E+10	2.8E+09			-3.6E+10	4.3E+08		
Incineration + car trsp	-1.6E+10	-1.4E+09	-5.7E+09	-1.2E+08				
Incineration	-2.0E+10	-2.0E+09	-7.3E+09	-1.4E+08	-2.2E+10	-2.7E+09	-7.9E+09	-1.4E+08
Landfill	-4.1E+09	-1.2E+09	-1.4E+09	3.3E+06	-5.2E+09	-1.2E+09	-1.8E+09	-8.5E+05
Non-renewable energy								
Rec dig h/e	-8.5E+09	8.8E+08	-5.4E+09	-4.2E+08	-1.5E+10	-1.3E+09	-7.4E+09	-4.4E+08
Rec dig f	-8.6E+09	7.4E+08			-1.5E+10	-1.5E+09		
Rec comp	-6.5E+09	2.8E+09			-1.3E+10	4.2E+08		
Incineration + car trsp	6.3E+09	1.4E+09	2.5E+09	2.7E+07				
Incineration	2.4E+09	8.4E+08	8.4E+08	7.7E+06	4.8E+08	1.3E+08	2.4E+08	7.5E+05
Landfill	-1.7E+09	-4.6E+08	-6.4E+08	4.3E+06	-2.9E+09	-6.7E+08	-9.9E+08	1.8E+05
Abiotic resources								
Rec dig h/e	-1.2E+09	1.2E+08	-7.6E+08	-5.8E+07	-2.1E+09	-1.9E+08	-1.0E+09	-6.2E+07
Rec dig f	-1.2E+09	1.0E+08			-2.1E+09	-2.1E+08		
Rec comp	-9.4E+08	3.9E+08			-1.8E+09	5.9E+07		
Incineration + car trsp	8.8E+08	2.0E+08	3.4E+08	3.7E+06				
Incineration	3.4E+08	1.2E+08	1.2E+08	1.1E+06	7.0E+07	1.8E+07	3.4E+07	1.2E+05
Landfill	-2.5E+08	-6.5E+07	-9.0E+07	5.9E+05	-4.0E+08	-1.2E+08	-1.4E+08	2.5E+04
Non-treated waste								
Rec dig h/e	-4.3E+07	-7.7E+06	-3.0E+07	-5.0E+06	-4.3E+07	-8.0E+06	-3.1E+07	-5.0E+06
Rec dig f	-3.6E+07	-7.4E+05			-3.6E+07	-1.1E+06		
Rec comp	-3.7E+07	-1.8E+06			-3.7E+07	-2.2E+06		
Incineration + car trsp	5.8E+06	1.2E+06	2.3E+06	2.6E+04				
Incineration	5.9E+06	1.2E+06	2.3E+06	2.7E+04	4.7E+06	7.2E+05	2.0E+06	2.3E+04
Landfill	-1.4E+07	-4.2E+06	-5.0E+06	-3.2E+03	-1.5E+07	-4.5E+06	-5.2E+06	-5.9E+03

7.5.2 Non-toxicological impacts

Concerning the impact category global warming medium transport distances and transports with passenger car does not affect the ranking for the whole system or for newspaper. For the food waste fraction incineration gets better than composting, which is better than landfill. Digestion stays the most preferable option. For PET, incineration with car transport has the most net emissions of greenhouse gases, exceeding the landfill alternative. The differences between the incineration alternatives and landfilling are for PET small. Recycling is preferable to them all.

The increased transports clearly influence the impact category photo-oxidant formation. Considering the whole system incineration is the preferable alternative if car transports are omitted. If they are included incineration however becomes the worst option. Recycling is still better than landfilling for the whole system. For food waste incineration is better than landfilling, which in turn is better than digestion and composting. For newspaper the ranking remains unchanged. For PET, recycling still gives the largest net avoided contribution to photo-oxidant formation and landfill is preferable over incineration if car transports are included in the incineration alternative.

Table 7.17 Comparison between a scenario with medium transports and the base scenario. The added transport distances are the same as in section 7.3 but for recycling, digestion, composting and incineration extra car transport of 1 km/kg treated waste is added. For incineration the alternative where no car transports are made is also shown. The table show weighted results in the unit is SEK/year. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	Medium transports + passenger car				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Global warming								
Rec dig h/e	-6.0E+07	1.6E+07	-1.6E+08	-3.9E+06	-2.4E+08	-4.6E+07	-2.2E+08	-4.6E+06
Rec dig f	-6.4E+07	1.2E+07			-2.4E+08	-5.0E+07		
Rec comp	-1.4E+06	7.4E+07			-1.8E+08	7.2E+06		
Incineration + car trsp	3.7E+08	4.4E+07	7.2E+07	5.6E+06				
Incineration	2.6E+08	2.8E+07	2.6E+07	5.1E+06	2.1E+08	8.8E+06	1.0E+07	4.9E+06
Landfill	8.8E+08	1.6E+08	2.6E+08	5.4E+06	8.5E+08	1.5E+08	2.5E+08	5.3E+06
Photo-oxidant formation max								
Rec dig h/e	2.4E+08	1.7E+08	1.3E+08	-3.4E+07	-2.0E+08	1.7E+07	-1.7E+07	-3.6E+07
Rec dig f	2.4E+08	1.6E+08			-2.0E+08	1.2E+07		
Rec comp	2.6E+08	1.8E+08			-1.9E+08	2.4E+07		
Incineration + car trsp	2.7E+08	5.7E+07	1.1E+08	1.0E+06				
Incineration	-4.6E+07	1.1E+07	-2.0E+07	-5.1E+05	-1.1E+08	-1.2E+07	-3.9E+07	-7.3E+05
Landfill	3.5E+08	8.9E+07	1.3E+08	3.2E+05	3.2E+08	7.6E+07	1.2E+08	1.8E+05
Acidification (excl NO_x and SO_x)								
Rec dig h/e	-2.9E+06	-1.8E+05	-6.2E+05	-5.1E+05	-2.9E+06	-1.9E+05	-6.3E+05	-5.1E+05
Rec dig f	-2.7E+06	1.8E+04			-2.7E+06	5.4E+03		
Rec comp	1.5E+06	4.2E+06			1.4E+06	4.1E+06		
Incineration + car trsp	-1.1E+06	9.3E+04	-5.2E+05	-9.4E+03				
Incineration	-1.2E+06	9.0E+04	-5.2E+05	-9.5E+03	-1.2E+06	8.4E+04	-5.3E+05	-9.6E+03
Landfill	2.1E+05	4.7E+05	-1.6E+05	-1.6E+02	2.0E+05	4.7E+05	-1.6E+05	-2.0E+02
Aquatic eutrophication (excl NO_x)								
Rec dig h/e	-2.0E+06	-3.1E+06	4.4E+05	-1.4E+04	-2.3E+06	-3.2E+06	3.2E+05	-1.6E+04
Rec dig f	-1.9E+06	-3.1E+06			-2.3E+06	-3.2E+06		
Rec comp	2.3E+06	1.2E+06			1.9E+06	1.0E+06		
Incineration + car trsp	6.6E+07	5.8E+07	7.2E+04	-1.8E+03				
Incineration	6.5E+07	5.8E+07	-2.2E+04	-2.9E+03	6.5E+07	5.8E+07	-6.0E+04	-3.3E+03
Landfill	9.5E+07	8.6E+07	6.4E+05	1.6E+03	9.5E+07	8.6E+07	6.2E+05	1.4E+03
SO_x								
Rec dig h/e	-2.5E+07	3.3E+06	-7.9E+06	-2.1E+06	-3.5E+07	-3.5E+05	-1.1E+07	-2.1E+06
Rec dig f	-2.6E+07	1.9E+06			-3.7E+07	-1.8E+06		
Rec comp	-2.6E+07	2.1E+06			-3.7E+07	-1.8E+06		
Incineration + car trsp	-9.1E+05	1.7E+06	-5.2E+05	-3.8E+04				
Incineration	-7.9E+06	6.2E+05	-3.4E+06	-7.1E+04	-1.0E+07	-2.3E+05	-4.2E+06	-8.0E+04
Landfill	3.6E+06	1.3E+06	1.1E+06	7.6E+03	2.2E+06	8.1E+05	6.3E+05	2.8E+03
NO_x								
Rec dig h/e	-3.6E+06	3.3E+07	-4.1E+07	-4.0E+06	-8.3E+07	2.3E+06	-6.5E+07	-4.4E+06
Rec dig f	3.9E+07	7.5E+07			-4.1E+07	4.5E+07		
Rec comp	1.1E+07	4.8E+07			-7.2E+07	1.4E+07		
Incineration + car trsp	9.5E+07	2.4E+07	4.8E+07	2.6E+05				
Incineration	6.2E+07	2.0E+07	3.4E+07	9.8E+04	9.4E+06	2.2E+05	1.7E+07	-9.0E+04
Landfill	3.7E+07	1.2E+07	1.2E+07	1.5E+05	6.5E+06	1.2E+06	2.6E+06	4.4E+04
NH_3 max								
Rec dig h/e	-1.4E+05	-2.1E+05	2.6E+05	3.3E+02	-1.6E+05	-2.2E+05	2.6E+05	2.2E+02
Rec dig f	8.4E+04	1.4E+04			5.8E+04	2.7E+03		
Rec comp	1.6E+07	1.6E+07			1.6E+07	1.6E+07		
Incineration + car trsp	-4.8E+06	2.7E+05	-2.2E+06	-3.8E+04				
Incineration	-4.8E+06	2.7E+05	-2.2E+06	-3.8E+04	-4.8E+06	2.6E+05	-2.2E+06	-3.8E+04
Landfill	1.9E+06	2.1E+06	-2.1E+05	-1.6E+02	1.9E+06	2.1E+06	-2.1E+05	-2.4E+02

The categories acidification (excl SO_x and NO_x), aquatic eutrophication (excl NO_x) and NH_3 are not very much affected by this scenario. For the SO_x impact category looking at the whole system landfill becomes better than incineration if car transports are made. The recycling alternatives still avoids the most emissions of SO_x. For food waste net emissions of SO_x are only avoided in the landfill alternative. Incineration has less net emissions than digestion where the gas is used as bus fuel, which has less net emissions than composting, which in turn has less emissions than digestion combined with heat and electricity production.

For the whole system emissions of NO_x are still avoided when recycling is combined with digestion with heat and electricity production. Recycling in combination with composting has the least net emission of NO_x. Landfill is here better than recycling combined with digestion where bus fuel is produced. The largest net emission considering the whole system occurs in the incineration alternative. For food waste landfill becomes better than incineration, digestion and composting still being worst off. For the PET fraction landfill becomes better than incineration when transports are made with passenger car.

7.5.3 Toxicological effects

The impact categories toxicological effects on ecosystems and human health are heavily influenced by the prolonged transport distances in combination with transports made by passenger cars (see Table 7.18). The ranking is changed in all cases except for assessing eco-toxicological effects using the USES min method.

Using the EDIP method the most contribution to the eco-toxicological impact category caused by passenger car transport comes from iron released to soil. Concerning the ranking landfill is better than incineration if transports with passenger car are considered. The recycling alternatives have the highest impact, except for PET for which it has the least.

For eco-toxicological effects assessed with the USES min method the most contribution from the use of passenger car are releases of vanadium to air. If the waste for incineration is transported by car, landfill becomes the better option for food waste and newspaper. For the whole system, incineration is however still preferred to landfilling, which in turn is better than the recycling options.

When using the USES max method the largest contributions to eco-toxicological effects caused by the passenger car come from barium emitted to water and from vanadium and selenium released to air. For the whole system landfill equals incineration without car transport and they rank higher than the recycling alternatives. Incineration with car transport on the other hand scores worse than recycling. For food waste landfill contributes the least to eco-toxicological effects followed by incineration. Digestion and composting are the worst alternatives. The newspaper fraction, if not transported by car, gives the least impact in the incineration alternative. If a car however is involved in the transportation of newspaper for incineration, landfill becomes the preferable option followed by recycling. For PET, recycling still gives an avoided burden. Landfill is better than incineration combined with car transport but not if the car trip is excluded.

For all of the three methods used to assess toxicological effects on human health the major contribution from transport by passenger car comes from NMVOC, here characterised as benzene. Regarding the whole system the ranking using either of the three methods goes from recycling better than incineration, better than landfill in the base scenario to incineration without car transport better than landfill, better than recycling, better than incineration with car transport. For food waste the three methods give the ranking landfill is better than incineration which is better than digestion, in turn better than composting. For newspaper landfill is better than recycling. Incineration is the best alternative for newspaper if no car transports are involved, while it is the worst if car transports are included. Recycling PET is still the preferable option but landfilling is better than incineration if car transports are included.

Table 7.18 Comparison between a scenario with medium transports and the base scenario. The added transport distances are the same as in section 7.3 but for recycling, digestion, composting and incineration extra car transport of 1 km/kg treated waste is also added. For incineration the alternative where no car transports are made is also shown. The table shows weighted results for toxicological effects in the unit SEK/year. The sub-categories are added together into eco-toxicological effects (E-tox) and toxicological effects on human health (H-tox).

	Medium transports and passenger car				**Base scenario**			
	Total	**Food waste**	**Newspaper**	**PET**	**Total**	**Food waste**	**Newspaper**	**PET**
E-tox EDIP								
Rec dig h/e	1.7E+08	6.1E+07	5.9E+07	-4.5E+05	-6.3E+06	2.0E+06	-1.9E+05	-1.1E+06
Rec dig f	1.7E+08	6.2E+07			-5.4E+06	2.9E+06		
Rec comp	1.8E+08	6.2E+07			-8.0E+06	3.9E+05		
Incineration + car trsp	1.2E+08	1.9E+07	5.1E+07	5.8E+05				
Incineration	-2.1E+07	-2.1E+06	-7.6E+06	-1.0E+05	-2.2E+07	-2.8E+06	-8.2E+06	-1.1E+05
Landfill	1.5E+06	-4.2E+04	4.0E+05	5.8E+04	3.4E+05	-4.5E+05	4.6E+04	5.4E+04
E-tox USESmin								
Rec dig h/e	8.9E+07	1.8E+08	-1.1E+08	-4.3E+04	-9.0E+07	1.2E+08	-1.7E+08	-7.3E+05
Rec dig f	1.4E+08	2.3E+08			-4.3E+07	1.7E+08		
Rec comp	1.3E+08	2.2E+08			-5.4E+07	1.6E+08		
Incineration + car trsp	-1.2E+08	-1.1E+07	-3.5E+07	-9.5E+05				
Incineration	-2.6E+08	-3.2E+07	-9.4E+07	-1.6E+06	-2.6E+08	-3.2E+07	-9.4E+07	-1.6E+06
Landfill	-1.0E+08	-3.1E+07	-3.6E+07	2.5E+04	-1.0E+08	-3.1E+07	-3.6E+07	2.2E+04
E-tox USESmax								
Rec dig h/e	2.1E+10	8.9E+09	6.4E+09	-3.0E+07	-1.2E+09	1.5E+09	-9.9E+08	-1.2E+08
Rec dig f	2.2E+10	9.2E+09			1.8E+09	-1.4E+09		
Rec comp	2.2E+10	9.5E+09			-9.3E+08	1.8E+09		
Incineration + car trsp	3.4E+10	4.9E+09	1.3E+10	2.7E+08				
Incineration	1.6E+10	2.3E+09	5.7E+09	1.8E+08	1.6E+10	2.2E+09	5.6E+09	1.8E+08
Landfill	1.6E+10	2.2E+09	5.8E+09	1.9E+08	1.6E+10	2.1E+09	5.7E+09	1.9E+08
H-tox EDIP								
Rec dig h/e	3.1E+08	3.5E+08	1.0E+08	-8.0E+07	-7.5E+08	-1.3E+07	-2.4E+08	8.4E+07
Rec dig f	3.6E+08	3.9E+08			-7.0E+08	3.2E+07		
Rec comp	3.9E+08	4.2E+08			-6.9E+08	3.9E+07		
Incineration + car trsp	5.9E+08	1.3E+08	2.5E+08	2.4E+06				
Incineration	-1.6E+08	1.8E+07	-6.8E+07	-1.3E+06	-3.1E+08	-3.5E+07	-1.1E+08	1.8E+06
Landfill	-7.7E+06	-4.6E+06	-7.6E+06	8.6E+05	-9.1E+07	-3.5E+07	-3.4E+07	5.6E+05
H-tox USESmin								
Rec dig h/e	1.3E+07	1.2E+07	9.5E+06	-3.4E+06	-2.0E+07	1.3E+06	-1.1E+06	3.5E+06
Rec dig f	1.3E+07	1.2E+07			-2.0E+07	9.6E+05		
Rec comp	1.5E+07	1.4E+07			-1.9E+07	1.7E+06		
Incineration + car trsp	2.4E+07	5.0E+06	9.9E+06	1.0E+05				
Incineration	1.6E+06	1.7E+06	3.3E+05	-8.3E+03	-3.9E+06	-3.6E+05	-1.4E+06	2.8E+04
Landfill	3.9E+06	1.2E+06	1.3E+06	1.9E+04	6.6E+05	3.2E+04	3.1E+05	7.1E+03
H-tox USESmax								
Rec dig h/e	3.0E+09	2.8E+09	2.1E+09	-7.7E+08	-4.4E+09	2.9E+08	-2.6E+08	8.0E+08
Rec dig f	2.9E+09	2.8E+09			-4.5E+09	2.2E+08		
Rec comp	3.3E+09	3.1E+09			-4.3E+09	3.9E+08		
Incineration + car trsp	5.5E+09	1.1E+09	2.2E+09	2.3E+07				
Incineration	3.5E+08	3.8E+08	7.5E+07	-1.9E+06	-8.9E+08	-8.2E+07	-3.1E+08	6.3E+06
Landfill	8.8E+08	2.7E+08	3.0E+08	4.2E+06	1.5E+08	7.3E+06	6.9E+07	1.6E+06

7.5.4 Total weighted results

When using Ecotax 98/EDIP the major additions to the total result from transports made by passenger car come from toxicological effects on human health caused by NMVOC and extraction of abiotic resources in the form of crude oil. Looking at the whole system recycling is still the best option but landfill becomes better than incineration if car transports are included in the incineration alternative. For food waste, incineration without car transports is better than landfill but not if car transport is included. Both are better than digestion, which in turn is better than composting of food waste. For newspaper and PET landfill becomes better than incineration if the car transports are included and recycling is still the best option.

The ranking for the whole system is unchanged compared to the base scenario when Ecotax 98/USESmin is applied. The major contribution to the total impact from the passenger car transports comes from eco-toxicological effects caused by emissions of vanadium and from emissions of CO_2. For food waste incineration is still the best alternative, while landfill has become the better alternative compared to digestion and composting. For newspaper the ranking remains the same as in the base scenario.

The largest contribution to the total result from the passenger car using Ecotax 98/USESmax come from toxicological effects caused by barium, selenium, vanadium and NMVOC. For the whole system incineration without car transport is a little bit better than landfill, which is better than the recycling alternatives. Incineration combined with car transports is however the worst option. For food waste the ranking is changed to landfill better than incineration, which is better than digestion and composting. For newspaper incineration without car transport is the treatment option with the lowest impact followed by landfill and recycling. Incineration combined with transport of newspaper with passenger car has the highest impact. For PET the ranking is the same as in the base scenario if no car transports are included in the incineration alternative. With car transports included incineration becomes worse than landfill.

Using Eco-indicator 99 most of the impact from passenger car transport is caused by effects of carcinogenic substances on human health from metallic ions. Impact on the resource fossil fuel from extraction of crude oil is also visible. The ranking is only altered compared to the base scenario for food waste where landfill equals incineration if combined with car transport.

7.19 Comparison between a scenario with medium transports and the base scenario. The added transport distances are the same as in section 7.3 but for recycling, digestion, composting and incineration extra car transport of 1 km/kg treated waste is also added. For incineration the alternative where no car transports are made is also shown. The results for all impact categories are weighted together. The Ecotax 98 method has been applied in the combinations EDIP max, USES min and USES max as described in section 6.3. The results for these are shown in SEK/year. The results from using the Eco-indicator 99 method are shown in points.

	Medium transports + passenger car				**Base scenario**			
	Total	Food waste	Newspaper	PET	Total	Food waste	Newspaper	PET
Total Ecotax 98/EDIPmax								
Rec dig h/e	-6.1E+08	7.4E+08	-7.1E+08	-1.9E+08	-3.4E+09	-2.4E+08	-1.6E+09	-2.0E+08
Rec dig f	-5.5E+08	8.0E+08			-3.4E+09	-1.7E+08		
Rec comp	-1.5E+08	1.2E+09			-3.1E+09	1.6E+08		
Incineration + car trsp	2.4E+09	5.3E+08	8.7E+08	1.3E+07				
Incineration	4.9E+08	2.5E+08	7.8E+07	4.3E+06	-9.4E+07	3.6E+07	-1.0E+08	2.2E+06
Landfill	1.1E+09	2.8E+08	3.0E+08	7.4E+06	7.6E+08	1.5E+08	1.9E+08	6.1E+06
Total Ecotax 98/USESmin								
Rec dig h/e	-8.8E+06	2.5E+08	-3.3E+08	-2.2E+07	-5.3E+08	6.8E+07	-4.9E+08	-2.5E+07
Rec dig f	8.1E+07	3.4E+08			-4.4E+08	1.6E+08		
Rec comp	1.2E+08	3.8E+08			-4.2E+08	1.8E+08		
Incineration + car trsp	4.7E+08	1.3E+08	1.1E+08	5.1E+06				
Incineration	1.3E+08	7.9E+07	-3.6E+07	3.5E+06	6.7E+06	3.4E+07	-7.4E+07	3.0E+06
Landfill	9.4E+08	2.3E+08	2.4E+08	5.6E+06	8.7E+08	2.1E+08	2.2E+08	5.4E+06
Total Ecotax 98/USESmax								
Rec dig h/e	2.3E+10	1.2E+10	7.7E+09	-9.1E+08	-8.3E+09	1.5E+09	-2.6E+09	-1.0E+09
Rec dig f	2.4E+10	1.2E+10			-8.1E+09	1.8E+09		
Rec comp	2.5E+10	1.3E+10			-7.6E+09	2.3E+09		
Incineration + car trsp	4.1E+10	6.4E+09	1.6E+10	3.0E+08				
Incineration	1.7E+10	2.9E+09	5.9E+09	1.9E+08	1.5E+10	2.2E+09	5.3E+09	1.8E+08
Landfill	1.8E+10	2.7E+09	6.4E+09	2.0E+08	1.7E+10	2.3E+09	6.0E+09	2.0E+08
Total Eco-indicator 99								
Rec dig h/e	-1.3E+07	2.9E+07	9.3E+05	-3.0E+06	-5.3E+07	1.6E+07	-1.2E+07	-3.2E+06
Rec dig f	-1.4E+07	2.9E+07			-5.3E+07	1.5E+07		
Rec comp	-7.6E+06	3.5E+07			-4.8E+07	2.0E+07		
Incineration + car trsp	9.6E+07	2.1E+07	3.2E+07	7.1E+05				
Incineration	7.2E+07	1.7E+07	2.1E+07	5.9E+05	6.0E+07	1.3E+07	1.8E+07	5.5E+05
Landfill	1.1E+08	2.1E+07	3.4E+07	8.4E+05	1.0E+08	1.8E+07	3.2E+07	8.1E+05

7.5.5 Summary

A final summary of the ranking of the waste management options in the scenario with medium transports and transports by passenger car, for the whole system, is given in Table 7.20.

Table 7.20 The ranking of the waste management options for the whole system for each impact category. When the three recycling alternatives are ranked in sequence they are reported as one. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling. In this scenario there are two incineration alternatives and when they are not ranked in sequence they are both reported, Inc/t for only medium transport and Inc/c for additional passenger car use.

Impact category	Ranking								
Total energy	Rec	<	Inc	<	Lf				
Non-renewable energy	Rec	<	Lf	<	Inc				
Abiotic resources	Rec	<	Lf	<	Inc				
Non-treated waste	Rec	<	Lf	<	Inc				
Global warming	Rec	<	Inc	<	Lf				
Photo-oxidant formation max	Inc/t	<	Lf	<	Rec	<	Inc/c		
Acidification (excl. SO_x and NO_x)	Rec/d	<	Inc	<	Lf	<	Rec/c		
Aquatic eutrophication (excl. NO_x)	Rec	<	Inc	<	Lf				
SO_x	Rec	<	Inc/t	<	Lf	<	Inc/c		
NO_x	Rec/d (he)	<	Rec/c	<	Lf	<	Rec/d (f)	<	Inc
NH_3 max	Inc	<	Rec/d	<	Lf	<	Rec/c		
E-tox EDIP	Inc/t	<	Lf	<	Inc/c	<	Rec		
E-tox USESmin	Inc	<	Lf	<	Rec				
E-tox USESmax	Lf=Inc/t	<	Rec	<	Inc/c				
H-tox EDIP	Inc/t	<	Lf	<	Rec	<	Inc/c		
H-tox USESmin	Inc/t	<	Lf	<	Rec	<	Inc/c		
H-tox USESmax	Inc/t	<	Lf	<	Rec	<	Inc/c		
Ecotax98 / EDIP	Rec	<	Inc/t	<	Lf	<	Inc/c		
Ecotax98 / USESmin	Rec	<	Inc	<	Lf				
Ecotax98 / USESmax	Inc/t	<	Lf	<	Rec	<	Inc/c		
Eco-indicator 99	Rec	<	Inc	<	Lf				

7.6 Results Scenario Natural gas for heat production

7.6.1 Introduction

In this scenario natural gas is assumed for the production of heat which is avoided by incinerating waste and combusting gas from digestion or landfilling. In the base scenario this avoided heat is produced from forest residues. Differences between this scenario and the base scenario are in general that the incineration, but also the landfilling and anaerobic digestion processes, are credited avoidance of a non-renewable fuel instead of a renewable. This is an advantage if focus is on abiotic resources and global warming. However, in other cases natural gas seems to be a more preferable alternative than forest residues from an environmental point of view. With the characterisation and weighting methods used here this may be said for the categories photo-oxidant formation, aquatic eutrophication (excl NO_x), acidification (excl SO_x and NO_x), SO_x, NO_x, NH_3, non-treated waste and the toxicological impact categories. The substances emitted from forest residues incineration with the largest toxicological effects modelled are different metals ending up in the ashes, which are spread in the forest and thereby emitted to soil. NMVOC is a major contributor to photo-oxidant formation and also to human toxicological impacts mainly in the Ecotax 98/USESmax case. A comparison between the two heat production alternatives are shown in Table 7.21, identifying which impact categories that are affected more by which alternative and also which substance is responsible for the major part of the impact.

Table 7.21 Heat from forest residues and natural gas respectively are compared. For each impact category the process with the highest value is marked and the substance contributing the most to the category is stated.

Impact category	**Heat from forest residues**	**Heat from natural gas**	**Substance contributing the most to the category**
Abiotic resources		X	Natural gas
Non-treated waste			
Global warming		X	CO_2
Photo-oxidant formation max	X		CO, NMVOC
Acidification (excl SO_x and NO_x)	X		NH_3
Aquatic eutrophication (excl NO_x)	X		NH_3
SO_x	X		
NO_x	X		
NH_3 max	X		
Eco. tox. EDIP	X		Cd, Zn to soil
Eco. tox. USESmin	X		Zn, Cr to soil
Eco. tox. USESmax	X		Ni, Cu, Zn, Cr to soil
Hum. tox. EDIP	X		As to soil
Hum. tox. USESmin	X		NMVOC to air
Hum. tox. USESmax	X		NMVOC to air
Ecotax 98/EDIP		X	Category: abiotic resources
Ecotax 98/USESmin		X	Category: global warming
Ecotax 98/USESmax	(X) very narrow	X	Category: abiotic resources (natural gas), E-tox and H-tox (forest residues)
Total Eco-indicator 99	(X) very narrow	X	Category: abiotic resources -fossil fuels (natural gas), E-tox and human health – carcinogenic (forest residues)

Results for the different categories and total weighted results are shown in Tables 7.22 – 26 for the whole system, food waste, newspaper and PET. Figures are shown both for the base scenario as a reference and for the natural gas scenario.

7.6.2 Energy, abitoic resources and non-treated waste

Only very marginal changes in the total energy balance compared to the base scenario occur when substituting forest residues with natural gas. When focusing on the non-renewable part of the energy more discernible changes can be seen. Incineration will for this impact category be ranked as the most preferable alternative for the whole system, because of the avoided heat production from natural gas. The non-renewable energy balance for landfilling is also improved, but not enough to become a better alternative than recycling. For PET the ranking in the case of non-renewable energy is incineration before recycling before landfilling. For newspaper, recycling is still ranked highest, but the difference compared to incineration is small. Landfilling is also for this fraction the least preferable option. Concerning food waste the ranking of waste management options will also be altered for this impact category. Incineration is the most preferable, followed by digestion with heat and electricity generation. Digestion with recovered gas used as bus fuel and landfilling is contributing equally to avoidance of non-renewable energy use, whereas the composting alternative still gives rise to a net use, since no heat production is avoided using this option.

The impact category abiotic resources consists to the larger part of the non-renewable energy sources and consequently the same changes appear for this category. The amounts of non-treated waste are only marginally altered compared to the base scenario.

Table 7.22 Weighted results for the impact categories total energy balance, non-renewable energy balance, abiotic resources and non-treated waste. The figures are in MJ/year for the energy categories and SEK/year for the others. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	Natural gas scenario				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Total energy								
Rec dig h/e	-3,8E+10	-2,1E+09	-2,2E+10	-4,4E+08	-3,8E+10	-2,2E+09	-2,2E+10	-4,4E+08
Rec dig f	-3,8E+10	-1,5E+09			-3,8E+10	-1,5E+09		
Rec comp	-3,6E+10	4,3E+08			-3,6E+10	4,3E+08		
Incineration	-2,0E+10	-2,5E+09	-7,2E+09	-1,3E+08	-2,2E+10	-2,7E+09	-7,9E+09	-1,4E+08
Landfill	-5,0E+09	-1,5E+09	-1,7E+09	-7,6E+05	-5,2E+09	-1,2E+09	-1,8E+09	-8,5E+05
Non-renewable energy								
Rec dig h/e	-1,7E+10	-2,1E+09	-7,4E+09	-4,4E+08	-1,5E+10	-1,3E+09	-7,4E+09	-4,4E+08
Rec dig f	-1,7E+10	-1,5E+09			-1,5E+10	-1,5E+09		
Rec comp	-1,5E+10	4,2E+08			-1,3E+10	4,2E+08		
Incineration	-2,0E+10	-2,5E+09	-7,2E+09	-1,3E+08	4,8E+08	1,3E+08	2,4E+08	7,5E+05
Landfill	-5,0E+09	-1,5E+09	-1,7E+09	-7,8E+05	-2,9E+09	-6,7E+08	-9,9E+08	1,8E+05
Abiotic resources								
Rec dig h/e	-2,5E+09	-3,0E+08	-1,0E+09	-6,2E+07	-2,1E+09	-1,9E+08	-1,0E+09	-6,2E+07
Rec dig f	-2,4E+09	-2,1E+08			-2,1E+09	-2,1E+08		
Rec comp	-2,1E+09	5,9E+07			-1,8E+09	5,9E+07		
Incineration	-2,8E+09	-3,5E+08	-1,0E+09	-1,8E+07	7,0E+07	1,8E+07	3,4E+07	1,2E+05
Landfill	-7,1E+08	-2,1E+08	-2,4E+08	-1,1E+05	-4,0E+08	-1,2E+08	-1,4E+08	2,5E+04
Non-treated waste								
Rec dig h/e	-4,3E+07	-8,0E+06	-3,0E+07	-5,0E+06	-4,3E+07	-8,0E+06	-3,1E+07	-5,0E+06
Rec dig f	-3,6E+07	-1,1E+06			-3,6E+07	-1,1E+06		
Rec comp	-3,7E+07	-2,2E+06			-3,7E+07	-2,2E+06		
Incineration	4,6E+06	7,0E+05	1,9E+06	2,2E+04	4,7E+06	7,2E+05	2,0E+06	2,3E+04
Landfill	-1,5E+07	-4,5E+06	-5,2E+06	-5,9E+03	-1,5E+07	-4,5E+06	-5,2E+06	-5,9E+03

7.6.3 Non-toxicological impacts

In the natural gas scenario the contribution to the global warming from incineration decreases substantially, it even results in a net avoidance of CO_2 equivalents. For the whole system this leads to a ranking where the recycling/digestion options are preferred before incineration, which is preferred before the recycling combined with composting of food waste. The difference is rather small between these four options. Landfilling is the only alternative with net greenhouse gas emissions. The change in the ranking of the alternatives is the same for food waste as for the whole system. For PET and newspaper no change in ranking occurs compared to the base scenario. The ranking is recycling before incineration before landfilling.

Heat produced from forest residues is responsible for a larger amount of photo-oxidant formation than heat produced from natural gas, mostly due to CO and NMVOC emissions. Compared to the base scenario incineration thus becomes less desirable concerning photo-oxidant formation in this scenario. This does not show as a change in the ranking, except for newspaper for which recycling here overtakes incineration. For PET and the whole system this was already the order of ranking in the base scenario.

Table 7.23 Weighted results for the impact categories global warming, photo-oxidant formation, acidification (excl SO_x and NO_x), aquatic eutrophication (excl NO_x), SO_x, NO_x and NH_3. The figures are in SEK/year. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	Natural gas scenario				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Global warming								
Rec dig h/e	-3,0E+08	-6,4E+07	-2,2E+08	-4,6E+06	-2,4E+08	-4,6E+07	-2,2E+08	-4,6E+06
Rec dig f	-2,8E+08	-5,0E+07			-2,4E+08	-5,0E+07		
Rec comp	-2,3E+08	7,2E+06			-1,8E+08	7,2E+06		
Incineration	-2,7E+08	-5,2E+07	-1,6E+08	1,9E+06	2,1E+08	8,8E+06	1,0E+07	4,9E+06
Landfill	8,0E+08	1,3E+08	2,3E+08	5,2E+06	8,5E+08	1,5E+08	2,5E+08	5,3E+06
Photo-oxidant formation max								
Rec dig h/e	-1,8E+08	2,2E+07	-1,7E+07	-3,6E+07	-2,0E+08	1,7E+07	-1,7E+07	-3,6E+07
Rec dig f	-1,9E+08	1,2E+07			-2,0E+08	1,2E+07		
Rec comp	-1,8E+08	2,3E+07			-1,9E+08	2,4E+07		
Incineration	1,9E+07	3,8E+06	7,1E+06	8,1E+04	-1,1E+08	-1,2E+07	-3,9E+07	-7,3E+05
Landfill	1,6E+09	8,0E+07	1,4E+09	1,9E+05	3,2E+08	7,6E+07	1,2E+08	1,8E+05
Acidification (excl SO_x and NO_x)								
Rec dig h/e	-2,7E+06	-1,3E+05	-6,3E+05	-5,1E+05	-2,9E+06	-1,9E+05	-6,3E+05	-5,1E+05
Rec dig f	2,6E+06	5,4E+03			-2,7E+06	5,4E+03		
Rec comp	1,6E+06	4,1E+06			1,4E+06	4,1E+06		
Incineration	4,1E+05	2,9E+05	4,5E+04	5,2E+02	-1,2E+06	8,4E+04	-5,3E+05	-9,6E+03
Landfill	3,6E+05	5,2E+05	-1,1E+05	-1,2E+02	2,0E+05	4,7E+05	-1,6E+05	-2,0E+02
Aquatic eutrophication (excl NO_x)								
Rec dig h/e	-2,3E+06	-3,2E+06	3,2E+05	-1,6E+04	-2,3E+06	-3,2E+06	3,2E+05	-1,6E+04
Rec dig f	-2,3E+06	-3,2E+06			-2,3E+06	-3,2E+06		
Rec comp	2,0E+06	1,0E+06			1,9E+06	1,0E+06		
Incineration	6,6E+07	5,8E+07	1,4E+05	1,3E+02	6,5E+07	5,8E+07	-6,0E+04	-3,3E+03
Landfill	9,5E+07	8,6E+07	6,4E+05	1,4E+03	9,5E+07	8,6E+07	6,2E+05	1,4E+03
SOx								
Rec dig h/e	-3,4E+07	1,7E+05	-1,1E+07	-2,1E+06	-3,5E+07	-3,5E+05	-1,1E+07	-2,1E+06
Rec dig f	-3,5E+07	-1,8E+06			-3,7E+07	-1,8E+06		
Rec comp	-3,5E+07	-1,7E+06			-3,7E+07	-1,8E+06		
Incineration	4,2E+06	1,6E+06	1,0E+06	1,2E+04	-1,0E+07	-2,3E+05	-4,2E+06	-8,0E+04
Landfill	3,7E+06	1,3E+06	1,1E+06	3,4E+03	2,2E+06	8,1E+05	6,3E+05	2,8E+03
NOx								
Rec dig h/e	-8,0E+07	3,3E+06	-6,5E+07	-4,4E+06	-8,3E+07	2,3E+06	-6,5E+07	-4,4E+06
Rec dig f	-3,8E+07	4,5E+07			-4,1E+07	4,5E+07		
Rec comp	-6,9E+07	1,4E+07			-7,2E+07	1,4E+07		
Incineration	3,7E+07	3,7E+06	2,7E+07	8,6E+04	9,4E+06	2,2E+05	1,7E+07	-9,0E+04
Landfill	9,4E+06	2,0E+06	3,6E+06	4,5E+04	6,5E+06	1,2E+06	2,6E+06	4,4E+04
NH_3 max								
Rec dig h/e	5,9E+05	2,1E+03	2,6E+05	2,2E+02	-1,6E+05	-2,2E+05	2,6E+05	2,2E+02
Rec dig f	6,0E+05	2,7E+03			5,8E+04	2,7E+03	2,6E+05	2,2E+02
Rec comp	1,6E+07	1,6E+07			1,6E+07	1,6E+07		
Incineration	1,2E+06	1,0E+06	3,7E+03	4,2E+01	-4,8E+06	2,6E+05	-2,2E+06	-3,8E+04
Landfill	2,5E+06	2,3E+06	2,8E+03	3,7E+01	1,9E+06	2,1E+06	-2,1E+05	-2,4E+02

The acidification (excl SO_x and NO_x) impact also becomes greater in this scenario, for all treatment options. The effect is that incineration and landfilling changes place in the ranking scheme for the whole system, newspaper and PET, in favour of landfilling. Giving the ranking recycling before landfilling before incineration. The ranking of the options for food waste is not affected.

A similar pattern results for SO_x, giving the ranking order recycling before landfilling before incineration. For the SO_x category the order of food waste management alternatives also changes to this ranking. For the NO_x category, landfilling was already ranked as second best to recycling in the base scenario for the whole system and for newspaper. In the natural gas scenario, this also becomes the ranking result for PET. For food waste the ranking for NO_x even results in landfill as the most preferred alternative, followed by digestion with heat and electricity production and incineration.

All options for the whole system have higher NH_3 emissions in the natural gas scenario, except for recycling/composting, which is unchanged. The ranking is also changed, resulting in the order recycling/digestion before incineration before landfilling before recycling combined with composting. This result is mainly caused by the food waste fraction, which has that same ranking (which is unchanged from the base scenario). In the base scenario avoided ammonia emissions from the combustion of forest residues also affected the whole system ranking. The absence of these also results in altered ranking of the waste management alternatives for newspaper and PET, placing landfilling before incineration and thereafter recycling concerning emissions of NH_3.

Only small changes can be seen for the impact category aquatic eutrophication (excl. SO_x and NO_x), and they do not lead to any altered rankings.

7.6.4 Toxicological impacts

With the assumptions of the natural gas scenario the ranking of waste management options for the category ecotoxicity comes out differently compared to the base scenario. Using the EDIP method, this is a result of incineration and also landfilling with heat production no longer being credited the avoidance of mainly emissions of cadmium and zinc to soil from ashes retrieved to the forest. Incineration is the most preferred option in the base scenario, for the whole system, newspaper and food waste (second best for PET) concerning ecotoxic effects using the EDIP method. Here, incineration turns from a net avoider to a net contributor for all fractions of waste. The order of ranking becomes recycling combined with composting, recycling combined with digestion, landfilling, incineration for the whole system and for the three fractions (for PET incineration and landfilling are equal).

With USESmin, incineration is ranked highest for the whole system, PET and food waste (second best for newspaper) in the base scenario with regard to ecotoxicological effects. In the natural gas scenario this changes and incineration ends up as the least preferred option for the whole system, newspaper and PET (second best for food waste). The reason that digestion and composting of food waste is still lower ranked than landfilling and incineration is the metal emissions from the digestion and composting residues used on farm land. These metal emissions (copper, chromium, mercury, zinc, etc) have a large part in making the ranking order for the whole system landfill before recycling before incineration, keeping the recycling alternatives on second place. For newspaper and PET, the ranking is opposite for recycling and landfilling.

Using the higher weighting factors of USESmax the recycling, digestion and composting alternatives are the most preferred alternatives, just as in the base scenario. This is because nickel and copper are highly weighted and they are emitted from landfilling of waste directly and from landfilling of ashes from waste incineration. These emissions are not affected by the changes made in this scenario. Incineration and landfilling are close in the comparison. In this case landfilling is slightly better, contrary to the base scenario.

Table 7.24 Weighted results for ecotoxicological impacts with two characterisation methods, EDIP and USES and two weighting levels minimum and maximum. The figures are in SEK/year. The sub-categories have been weighted and added together into eco-toxicological effects (E-tox).

	Natural gas scenario				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
E-tox EDIP								
Rec dig h/e	-3,1E+06	3,0E+06	-1,9E+05	-1,1E+06	-6,3E+06	2,0E+06	-1,9E+05	-1,1E+06
Rec dig f	-3,1E+06	2,9E+06			-5,4E+06	2,9E+06		
Rec comp	-5,7E+06	3,9E+05			-8,0E+06	3,9E+05		
Incineration	3,3E+06	4,5E+05	1,1E+06	5,5E+04	-2,2E+07	-2,8E+06	-8,2E+06	-1,1E+05
Landfill	3,0E+06	3,4E+05	9,7E+05	5,5E+04	3,4E+05	-4,5E+05	4,6E+04	5,4E+04
E-tox USES min								
Rec dig h/e	-5,3E+07	1,3E+08	-1,7E+08	-7,3E+05	-9,0E+07	1,2E+08	-1,7E+08	-7,3E+05
Rec dig f	-1,7E+07	1,7E+08			-4,3E+07	1,7E+08		
Rec comp	-2,8E+07	1,6E+08			-5,4E+07	1,6E+08		
Incineration	3,5E+07	4,9E+06	1,2E+07	2,3E+05	-2,6E+08	-3,2E+07	-9,4E+07	-1,6E+06
Landfill	-7,1E+07	-2,2E+07	-2,6E+07	3,6E+04	-1,0E+08	-3,1E+07	-3,6E+07	2,2E+04
E-tox USES max								
Rec dig h/e	-9,7E+08	1,5E+09	-9,9E+08	-1,2E+08	-1,2E+09	1,5E+09	-9,9E+08	-1,2E+08
Rec dig f	-7,7E+08	1,7E+09			-1,8E+09	1,9E+09		
Rec comp	-7,6E+08	1,8E+09			-9,3E+08	1,8E+09		
Incineration	1,8E+10	2,4E+09	6,3E+09	1,9E+08	1,6E+10	2,2E+09	5,6E+09	1,8E+08
Landfill	1,6E+10	2,2E+09	5,8E+09	1,9E+08	1,6E+10	2,1E+09	5,7E+09	1,9E+08

Alterations in the human toxicological impact category are mainly concerning the incineration alternative, but also to a lesser extent landfilling. Using the EDIP method the explanation to the decrease in preference for incineration is that avoided emissions of arsenic to soil from ashes retrieved to the forest are not credited the process any more. Neither are avoided emissions of NMVOC to air. Major contributors to this impact category using EDIP are instead emissions of dioxins to water (during RT), emissions of mercury to air, and of NMVOC to air. The dioxins originate from the landfilling of ashes and the mercury from the electricity generated for use in the incineration process. NMVOC is emitted from the trucks transporting waste to the incineration facility. The ranking still keeps recycling first, but landfilling overtakes incineration in this scenario.

USESmin and USESmax give the same rankings for human toxicology in the base scenario and changing to natural gas also results in the same changes in rankings. The whole system and the PET fraction keep their order of preference, recycling before incineration before landfilling. Newspaper switches recycling and incineration so that recycling is first in order, giving the same ranking as for PET and the whole system. The switch in the case of food waste gives the ranking recycling before landfilling before incineration. The major changes in impact using these methods result mainly from emissions of NMVOC and dioxins, with the origins as described above.

Table 7.25 Weighted results for human toxicological impacts with two characterisation methods, EDIP and USES and two weighting levels, minimum and maximum. The figures are in SEK/year. The sub-categories have been weighted and added together into toxicological effects on human health (H-tox).

	Natural gas scenario				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
H-tox EDIP								
Rec dig h/e	-6,9E+08	2,5E+06	-2,4E+08	-8,4E+07	-7,5E+08	-1,3E+07	-2,4E+08	-8,4E+07
Rec dig f	-6,6E+08	3,2E+07			-7,0E+08	3,2E+07		
Rec comp	-6,5E+08	3,9E+07			-6,9E+08	3,9E+07		
Incineration	1,1E+08	1,8E+07	4,0E+07	8,7E+05	-3,1E+08	-3,5E+07	-1,1E+08	-1,8E+06
Landfill	-4,8E+07	-2,2E+07	-1,9E+07	5,8E+05	-9,1E+07	-3,5E+07	-3,4E+07	5,6E+05
H-tox USES min								
Rec dig h/e	-1,9E+07	1,4E+06	-1,1E+06	-3,5E+06	-2,0E+07	1,3E+06	-1,1E+06	-3,5E+06
Rec dig f	-1,9E+07	9,6E+05			-2,0E+07	9,6E+05		
Rec comp	-1,9E+07	1,7E+06			-1,9E+07	1,7E+06		
Incineration	1,1E+06	2,7E+05	4,4E+05	4,0E+03	-3,9E+06	-3,6E+05	-1,4E+06	-2,8E+04
Landfill	1,2E+06	1,9E+05	4,9E+05	7,3E+03	6,6E+05	3,2E+04	3,1E+05	7,1E+03
H-tox USES max								
Rec dig h/e	-4,3E+09	3,3E+08	-2,6E+08	-8,0E+08	-4,4E+09	2,9E+08	-2,6E+08	-8,0E+08
Rec dig f	-4,4E+09	2,2E+08			-4,5E+09	2,2E+08		
Rec comp	-4,2E+09	3,9E+08			-4,3E+09	3,9E+08		
Incineration	2,5E+08	6,2E+07	1,0E+08	9,1E+05	-8,9E+08	-8,2E+07	-3,1E+08	-6,3E+06
Landfill	2,7E+08	4,2E+07	1,1E+08	1,7E+06	1,5E+08	7,3E+06	6,9E+07	1,6E+06

7.6.5 Total weighted results

There are no changes in the rankings of total weighted results for the whole system or the three fractions studied separately, independent of method used. One minor exception is that for food waste with Ecotax 98/EDIP incineration takes a step up to second place after digestion with heat and electricity generation, leaving digestion with biogas used as bus fuel as third in order.

However, there are changes for incineration regarding which the major impact categories contributing to the total weighted results are. Using the Ecotax 98/EDIP method abiotic resources and global warming are the two categories in this case dominating the totals. For the whole system and for the paper and food wastes they both sum up to net avoided effects. Plastic fractions have net emissions of greenhouse gases and net avoided abiotic resource use. This is because the waste is not accounted for as a resource used, but CO_2 emissions arising from the waste are included. Generally the values for abiotic resources are one order of magnitude larger than the values for global warming. With Ecotax 98/USESmin the lower weighting for abiotic resources is used, which is zero. In this case the global warming will constitute the major part of the totals for incineration, except for food waste where phosphorous emissions give rise to a high value for aquatic eutrophication (excl SO_x and NO_x). With Ecotax 98/USESmax toxicological impacts, but also to some extent abiotic resources constitute the major part of the total weighted results.

Using the Eco-indicator 99 for weighting gives a result which is very much the same as in the base scenario. This is because the dominating impact is chromium contributing to the impact category human health – carcinogenic and the changed assumption regarding the source of the avoided heat produced does not affect this dominance.

Table 7.26 Total weighted results with two different characterisation methods for toxicological impacts EDIP and USES and two weighting levels within the Ecotax 98 weighting method, minimum and maximum. The figures for the Ecotax 98 results are in SEK/year. In addition results weighted with the Eco-indicator 99 are presented, these are in points/year.

	Natural gas scenario				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Total Ecotax98/ EDIP								
Rec dig h/e	-3,8E+09	-3,4E+08	-1,6E+09	-2,0E+08	-3,4E+09	-2,4E+08	-1,6E+09	-2,0E+08
Rec dig f	-3,6E+09	-1,7E+08			-3,4E+09	-1,7E+08		
Rec comp	-3,3E+09	1,6E+08			-3,1E+09	1,6E+08		
Incineration	-2,9E+09	-3,1E+08	-1,1E+09	-1,5E+07	-9,4E+07	3,6E+07	-1,0E+08	2,2E+06
Landfill	1,7E+09	6,6E+07	1,4E+09	6,0E+06	7,6E+08	1,5E+08	1,9E+08	6,1E+06
Total Ecotax98/ USES min								
Rec dig h/e	-5,5E+08	6,3E+07	-4,9E+08	-2,5E+07	-5,3E+08	6,8E+07	-4,9E+08	-2,5E+07
Rec dig f	-4,5E+08	1,6E+08			-4,4E+08	1,6E+08		
Rec comp	-4,3E+08	1,8E+08			-4,2E+08	1,8E+08		
Incineration	-1,2E+08	1,8E+07	-1,2E+08	2,2E+06	6,7E+06	3,4E+07	-7,4E+07	3,0E+06
Landfill	9,8E+08	2,0E+08	3,4E+08	5,3E+06	8,7E+08	2,1E+08	2,2E+08	5,4E+06
Total Ecotax98/ USES max								
Rec dig h/e	-8,4E+09	1,5E+09	-2,6E+09	-1,0E+09	-8,3E+09	1,5E+09	-2,6E+09	-1,0E+09
Rec dig f	-8,1E+09	1,8E+09			-8,1E+09	1,8E+09		
Rec comp	-7,6E+09	2,3E+09			-7,6E+09	2,3E+09		
Incineration	1,5E+10	2,2E+09	5,3E+09	1,8E+08	1,5E+10	2,2E+09	5,3E+09	1,8E+08
Landfill	1,8E+10	2,3E+09	7,3E+09	2,0E+08	1,7E+10	2,3E+09	6,0E+09	2,0E+08
Eco-indicator 99								
Rec dig h/e	-5,4E+07	1,5E+07	-1,2E+07	-3,2E+06	-5,25E+07	1,57E+07	-1,16E+07	-3,18E+06
Rec dig f	-5,4E+07	1,5E+07			-5,32E+07	1,49E+07		
Rec comp	-4,9E+07	2,0E+07			-4,80E+07	2,02E+07		
Incineration	4,7E+07	1,1E+07	1,3E+07	4,7E+05	6,03E+07	1,28E+07	1,79E+07	5,52E+05
Landfill	1,0E+08	1,8E+07	3,1E+07	8,1E+05	1,02E+08	1,81E+07	3,19E+07	8,13E+05

7.6.6 Summary

A final summary of the ranking of the waste management options in the scenario using natural gas for heat production, for the whole system, is given in Table 7.27.

Table 7.27 The ranking of the waste management options for the whole system for each impact category. When the three recycling alternatives are ranked in sequence they are reported as one. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling.

Impact category	**Ranking**						
Total energy	Rec	<	Inc	<	Lf		
Non-renewable energy	Inc	<	Rec	<	Lf		
Abiotic resources	Inc	<	Rec	<	Lf		
Non-treated waste	Rec	<	Lf	<	Inc		
Global warming	Rec/d	<	Inc	<	Rec/c	<	Lf
Photo-oxidant formation max	Rec	<	Inc	<	Lf		
Acidification (excl. SO_x and NO_x)	Rec/d	<	Lf	<	Inc	<	Rec/c
Aquatic eutrophication (excl. NO_x)	Rec	<	Inc	<	Lf		
SO_x	Rec	<	Lf	<	Inc		
NO_x	Rec	<	Lf	<	Inc		
NH_3 max	Rec/d	<	Inc	<	Lf	<	Rec/c
E-tox EDIP	Rec	<	Lf	<	Inc		
E-tox USESmin	Lf	<	Rec	<	Inc		
E-tox USESmax	Rec	<	Lf	<	Inc		
H-tox EDIP	Rec	<	Lf	<	Inc		
H-tox USESmin	Rec	<	Inc	<	Lf		
H-tox USESmax	Rec	<	Inc	<	Lf		
Ecotax 98/ EDIP	Rec	<	Inc	<	Lf		
Ecotax 98/ USESmin	Rec	<	Inc	<	Lf		
Ecotax 98/ USESmax	Rec	<	Inc	<	Lf		
Eco-indicator 99	Rec	<	Inc	<	Lf		

7.7 Results Scenario Saved forest used for heat production

7.7.1 Introduction

In this scenario the biomass saved from virgin paper production when recycling the waste paper fractions is used for heat production. Heat production from natural gas is avoided. The changed assumptions of this scenario will thus only affect the recycling alternative.

The general consequences are that for the paper fractions, and thereby for a large part of the whole system, the potential impacts of incinerating forest residues will be added corresponding to the amount of biomass saved when recycling the waste. The same amount of heat produced from natural gas and associated environmental impacts will be subtracted, as an avoided heat source. This will lead to results more similar to the base scenario, as compared to the natural gas scenario. In Table 7.21 the differences between the two heat production systems are described roughly. There, it is made seen for which impact categories it will be of advantage or disadvantage to use forest residues for heat production instead of natural gas.

Changes in the rankings for newspaper and for the whole system compared to the natural gas scenario are described in the following. In Tables 7.28 - 31, figures for the two other paper fractions are also shown. One of the three recycling options for the whole system, recycling combined with digestion with heat and electricity production, is chosen for study here, since the food waste category is not affected. Results from the saved forest scenario are presented for this recycling alternative. The results are compared to the natural gas scenario results of the same recycling alternative, incineration and landfilling.

7.7.2 Energy, abiotic resources and non-treated waste

Only minor differences in the total energy budgets appear. The division between the non-renewable and the renewable part is however altered. In this scenario more non-renewable energy in the form of natural gas is saved in the recycling alternative and recycling is consequently ranked as the first option for the whole system and for newspaper (a change only for the whole system). Natural gas also constitutes a major part of the abiotic resources impact category and the same results are seen there. The category non-treated waste does not show any major changes compared to the natural gas scenario.

Table 7.28 Weighted results for the impact categories total energy balance, non-renewable energy balance, abiotic resources and non-treated waste. The figures are in MJ/year for the energy categories and SEK/year for the others. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor. The results for the recycling alternative in the saved forest scenario are marked SF and data are presented for the whole system and separately for the three paper fractions that are affected. As reference, figures from the natural gas scenario are also presented for recycling with digestion with heat and electricity production, incineration and landfilling.

Scenario Saved forest compared to Scenario Natural gas				
	Whole system	Newspaper	Mixed cardboard	Corrugated cardboard
Total energy				
Rec dig h/e SF	-3,7E+10	-2,1E+10	-2,4E+09	-3,9E+09
Rec dig h/e	-3,8E+10	-2,2E+10	-2,5E+09	-4,0E+09
Incineration	-2,0E+10	-7,2E+09	-2,0E+09	-3,4E+09
Landfill	-5,0E+09	-1,7E+09	-5,7E+08	-1,2E+09
Non-renewable energy				
Rec dig h/e SF	-2,7E+10	-1,4E+10	-2,2E+09	-1,4E+09
Rec dig h/e	-1,7E+10	-7,4E+09	-7,3E+08	4,0E+08
Incineration	-2,0E+10	-7,2E+09	-2,0E+09	-3,4E+09
Landfill	-5,0E+09	-1,7E+09	-5,7E+08	-1,2E+09
Abiotic Resources				
Rec dig h/e SF	-3,8E+09	-1,9E+09	-3,4E+08	-1,9E+08
Rec dig h/e	-2,5E+09	-1,0E+09	-1,2E+08	5,8E+07
Incineration	-2,8E+09	-1,0E+09	-2,8E+08	-4,8E+08
Landfill	-7,1E+08	-2,4E+08	-7,9E+07	-1,6E+08
Non-treated Waste				
Rec dig h/e SF	-4,3E+07	-3,1E+07	3,8E+05	-5,5E+06
Rec dig h/e	-4,3E+07	-3,1E+07	3,9E+05	-5,5E+06
Incineration	4,6E+06	1,9E+06	5,3E+05	9,1E+05
Landfill	-1,5E+07	-5,2E+06	-1,7E+06	-3,4E+06

7.7.3 Non-toxicological impacts

Greenhouse gas emissions are avoided when using a renewable fuel instead of a non-renewable. The ranking is not changed since recycling is ranked highest already in the natural gas scenario, but an enlargement of the difference between recycling and the other options is achieved.

The photo-oxidant formation is increased for the recycling alternative in this scenario because of emissions of CO and NMVOC arising from combustion of biofuels. This results in an altered ranking of the waste management options compared to the natural gas scenario for newspaper. Incineration becomes the most preferred option followed by recycling. The ranking for the whole system is not affected.

For the categories acidification (excl SO_x and NO_x), aquatic eutrophication (excl NO_x), SO_x and NO_x the recycling alternative gets slightly lower avoidance of potential impacts, but no changes in the rankings for newspaper or the whole system result.

Table 7.29 Weighted results for the impact categories global warming, photo-oxidant formation, acidification (excl SO_x and NO_x), aquatic eutrophication (exc. NO_x), SO_x, NO_x and NH_3. The figures are in SEK/year. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor. The results for the recycling alternative in the saved forest scenario are marked SF and data are presented for the whole system and separately for the three paper fractions that are affected. As reference, figures from the natural gas scenario are also presented for recycling with digestion with heat and electricity production, incineration and landfilling.

	Scenario Saved forest compared to Scenario Natural gas			
	Whole system	Newspaper	Mixed cardboard	Corrugated cardboard
Global warming				
Rec dig h/e SF	-5,2E+08	-3,6E+08	-3,5E+07	-5,3E+07
Rec dig h/e	-3,0E+08	-2,2E+08	-2,3E+04	-1,2E+07
Incineration	-2,7E+08	-1,6E+08	-1,5E+07	-8,1E+07
Landfill	8,0E+08	2,3E+08	1,2E+08	1,5E+08
Photo-oxidant formation max				
Rec dig h/e SF	-1,3E+08	2,1E+07	-3,8E+06	3,2E+07
Rec dig h/e	-1,8E+08	-1,7E+07	-1,3E+07	2,1E+07
Incineration	1,9E+07	7,1E+06	2,6E+06	3,6E+06
Landfill	1,6E+09	1,4E+09	3,9E+07	7,9E+07
Acidification (excl SOx and NOx)				
Rec dig h/e SF	-2,0E+06	-1,5E+05	1,2E+05	-6,6E+05
Rec dig h/e	-2,7E+06	-6,3E+05	-1,3E+03	-7,9E+05
Incineration	4,1E+05	4,5E+04	4,9E+04	2,1E+04
Landfill	3,6E+05	-1,1E+05	2,8E+04	-6,9E+04
Aquatic eutrophication (excl NOx)				
Rec dig h/e SF	-2,0E+06	4,8E+05	-1,5E+06	-1,2E+06
Rec dig h/e	-2,3E+06	3,2E+05	-1,5E+06	-1,2E+06
Incineration	6,6E+07	1,4E+05	5,6E+06	7,2E+04
Landfill	9,5E+07	6,4E+05	8,6E+06	4,1E+05
SOx				
Rec dig h/e SF	-2,7E+07	-6,9E+06	-3,3E+06	-8,5E+06
Rec dig h/e	-3,4E+07	-1,1E+07	-4,4E+06	-9,8E+06
Incineration	4,2E+06	1,0E+06	7,7E+05	4,8E+05
Landfill	3,7E+06	1,1E+06	4,8E+05	7,3E+05
NOx				
Rec dig h/e SF	-6,7E+07	-5,7E+07	-5,8E+06	2,0E+07
Rec dig h/e	-8,0E+07	-6,5E+07	-7,8E+06	1,8E+07
Incineration	3,7E+07	2,7E+07	8,1E+05	3,5E+06
Landfill	9,4E+06	3,6E+06	9,6E+05	1,7E+06
NH3 max				
Rec dig h/e SF	3,4E+06	2,1E+06	4,6E+05	7,9E+05
Rec dig h/e	5,9E+05	2,6E+05	2,4E+04	2,7E+05
Incineration	1,2E+06	3,7E+03	1,4E+05	1,7E+03
Landfill	2,5E+06	2,8E+03	2,3E+05	1,2E+03

Ammonia emissions are a lot higher for heat produced from forest residues than from natural gas. The ranking of the options for the whole system changes so that incineration is the first choice before landfilling, and recycling becomes the last alternative.

7.7.4 Toxicological impacts

Generally, from a toxicological point of view, results in this study indicate that heat from natural gas is preferred to heat from forest residues.

For the impact category eco-toxicology the main contributors are metals emitted to soil via spreading of ashes from the biofuel incineration. The consequences for the rankings are, using the EDIP method that the recycling alternative falls from highest to lowest ranking, both for newspaper and for the whole system. Using USESmin only the ranking for the whole system changes, the recycling alternative is lowered to become the last choice. With USESmax other toxicological issues are weighted higher and changes in this scenario do not affect the rankings.

Table 7.30 Weighted results for eco-toxicological impacts with two characterisation methods, EDIP and USES and two weighting levels minimum and maximum. The figures are in SEK/year. The sub-categories are weighted and added together into eco -toxicological effects (E-tox). The results for the recycling alternative in the saved forest scenario are marked SF and data are presented for the whole system and separately for the three paper fractions that are affected. As reference, figures from the natural gas scenario are also presented for recycling with digestion with heat and electricity production, incineration and landfilling.

	Scenario Saved forest compared to Scenario Natural gas			
	Whole system	Newspaper	Mixed cardboard	Corrugated cardboard
E-tox EDIP				
Rec dig h/e SF	8,8E+06	7,6E+06	1,5E+06	2,8E+06
Rec dig h/e	-3,1E+06	-1,9E+05	-3,8E+05	5,7E+05
Incineration	3,3E+06	1,1E+06	2,6E+05	2,0E+05
Landfill	3,0E+06	9,7E+05	2,2E+05	1,2E+05
E-tox USES min				
Rec dig h/e SF	8,2E+07	-8,1E+07	1,7E+07	-2,1E+06
Rec dig h/e	-5,3E+07	-1,7E+08	-3,9E+06	-2,8E+07
Incineration	3,5E+07	1,2E+07	3,9E+06	9,1E+06
Landfill	-7,1E+07	-2,6E+07	-8,2E+06	-1,5E+07
E-tox USES max				
Rec dig h/e SF	-9,6E+07	-4,2E+08	-1,8E+09	-1,2E+08
Rec dig h/e	-9,7E+08	-9,9E+08	-1,9E+09	-2,9E+08
Incineration	1,8E+10	6,3E+09	1,9E+09	2,2E+09
Landfill	1,6E+10	5,8E+09	1,8E+09	1,9E+09

Metals emitted to soil, as described for eco-toxicological impacts, are the main contributors to human toxicological impacts also, using the EDIP method. More precisely it is arsenic in the ashes that is concerned here. No changes in the ranking compared to the natural gas scenario arise, but the result for newspaper recycling, which indicates an avoidance of these effects, is halved. Human toxicology impacts are dominated by NMVOC with the USES methods The rankings are not altered, but for newspaper there is a change from avoiding human toxicological impacts to giving rise to them.

Table 7.31 Weighted results for human toxicological impacts with two characterisation methods, EDIP and USES and two weighting levels, minimum and maximum. The figures are in SEK/year. The sub-categories are weighted and added together into toxicological effects on human health (H-tox). The results for the recycling alternative in the saved forest scenario are marked SF and data are presented for the whole system and separately for the three paper fractions that are affected. As reference, figures from the natural gas scenario are also presented for recycling with digestion with heat and electricity production, incineration and landfilling.

	Scenario Saved forest compared to Scenario Natural gas			
	Whole system	Newspaper	Mixed cardboard	Corrugated cardboard
H-tox EDIP				
Rec dig h/e SF	-5,0E+08	-1,2E+08	4,9E+06	4,0E+07
Rec dig h/e	-6,9E+08	-2,4E+08	-2,6E+07	4,1E+06
Incineration	1,1E+08	4,0E+07	1,2E+07	2,3E+07
Landfill	-4,8E+07	-1,9E+07	-6,7E+06	-1,4E+07
H-tox USES min				
Rec dig h/e SF	-1,7E+07	3,7E+05	-7,3E+05	1,4E+06
Rec dig h/e	-1,9E+07	-1,1E+06	-1,1E+06	1,0E+06
Incineration	1,1E+06	4,4E+05	1,4E+05	2,0E+05
Landfill	1,2E+06	4,9E+05	1,3E+05	2,0E+05
H-tox USES max				
Rec dig h/e SF	-3,8E+09	8,3E+07	-1,7E+08	3,2E+08
Rec dig h/e	-4,3E+09	-2,6E+08	-2,5E+08	2,3E+08
Incineration	2,5E+08	1,0E+08	3,1E+07	4,5E+07
Landfill	2,7E+08	1,1E+08	2,9E+07	4,6E+07

7.7.5 Total weighted results

For the total weightings no changes in rankings result from using saved biomass for heat production, avoiding heat produced from natural gas. The results for recycling indicate a greater avoidance of environmental impacts in this scenario with all methods compared to the natural gas scenario.

Table 7.32 Total weighted results with two different characterisation methods for toxicological impacts EDIP and USES and two weighting levels within the Ecotax 98 weighting method, minimum and maximum. The figures for the Ecotax 98 results are in SEK/year. In addition results weighted with the Eco-indicator 99 are presented, these are in points/year.

	Scenario Saved forest compared to Scenario Natural gas			
	Whole system	**Newspaper**	**Mixed cardboard**	**Corrugated cardboard**
Total Ecotax 98/ EDIP max				
Rec dig h/e SF	-5,1E+09	-2,5E+09	-3,8E+08	-1,7E+08
Rec dig h/e	-3,8E+09	-1,6E+09	-1,8E+08	7,3E+07
Incineration	-2,9E+09	-1,1E+09	-2,7E+08	-5,3E+08
Landfill	1,7E+09	1,4E+09	8,1E+07	5,0E+07
Total Ecotax 98/ USES min				
Rec dig h/e SF	-6,1E+08	-5,3E+08	-2,9E+07	-3,5E+07
Rec dig h/e	-5,5E+08	-4,9E+08	-2,0E+07	-3,5E+07
Incineration	-1,2E+08	-1,2E+08	-2,7E+06	-6,6E+07
Landfill	9,8E+08	3,4E+08	1,2E+08	1,4E+08
Total Ecotax 98/ USES max				
Rec dig h/e SF	-8,4E+09	-2,7E+09	-2,3E+09	-8,1E+06
Rec dig h/e	-8,4E+09	-2,6E+09	-2,3E+09	5,8E+06
Incineration	1,5E+10	5,3E+09	1,7E+09	1,7E+09
Landfill	1,8E+10	7,3E+09	1,9E+09	2,0E+09
Total Eco-indicator 98				
Rec dig h/e SF	-6,0E+07	-1,6E+07	-7,5E+06	-5,9E+06
Rec dig h/e	-5,4E+07	-1,2E+07	-6,6E+06	-4,8E+06
Incineration	4,7E+07	1,3E+07	1,4E+07	1,6E+06
Landfill	9,2E+07	2,9E+07	1,8E+07	1,0E+07

7.7.6 Summary

A final summary of the ranking of the waste management options for the whole system is given in Table 7.33.

Table 7.33 The ranking of the waste management options for the whole system for each impact category. When the three recycling alternatives are very close these are reported as one. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling.

Impact category	Ranking						
Total energy	Rec	<	Inc	<	Lf		
Non-renewable energy	Rec	<	Inc	<	Lf		
Abiotic resources	Rec	<	Inc	<	Lf		
Non-treated waste	Rec	<	Lf	<	Inc		
Global warming	Rec	<	Inc	<	Lf		
Photo-oxidant formation max	Rec	<	Inc	<	Lf		
Acidification (excl. SO_x and NO_x)	Rec/d	<	Lf	<	Inc	<	Rec/c
Aquatic eutrophication (excl. NO_x)	Rec	<	Inc	<	Lf		
SO_x	Rec	<	Lf	<	Inc		
NO_x	Rec	<	Lf	<	Inc		
NH_3 max	Inc	<	Lf	<	Rec		
E-tox EDIP	Lf	<	Inc	<	Rec		
E-tox USESmin	Lf	<	Inc	<	Rec		
E-tox USESmax	Rec	<	Lf	<	Inc		
H-tox EDIP	Rec	<	Lf	<	Inc		
H-tox USESmin	Rec	<	Inc	<	Lf		
H-tox USESmax	Rec	<	Inc	<	Lf		
Ecotax 98/ EDIP	Rec	<	Inc	<	Lf		
Ecotax 98/ USESmin	Rec	<	Inc	<	Lf		
Ecotax 98/ USESmax	Rec	<	Inc	<	Lf		
Eco-indicator 99	Rec	<	Inc	<	Lf		

7.8 Results Scenario Surveyable Time period (ST)

7.8.1 Introduction

In this scenario the time boundary is set after the first 100 years have passed (the so called surveyable time period, ST). Emissions thus excluded are mainly from landfilling of waste and ashes, but also emissions of metals to soil from ashes from incinerated forest residues retrieved to the forest. When omitting emissions occurring after the surveyable time period, changes in the ranking of waste management options result for some impact categories. General reflections are that, compared to the base scenario, recycling is only marginally affected, since landfilling is sparsely used in combination with the recycling options. Incineration may be worse or better off in this scenario depending on impact category and weighting. RT-emissions (emissions occurring subsequent to the ST) are both avoided and contributed to in the incineration option. They originate from ashes, which are put into landfills or avoided ashes from the biofuel retrieved to the forest.

Landfilling will, in general, be credited in this scenario. However, some credit for avoided RT-emissions from the avoided heat production ashes are lost.

Energy balances and abiotic resource use will not be altered since only emissions are affected in this scenario. No changes occur in the SO_x, NO_x or non-treated waste categories either, since no emissions are defined as RT-emissions in these. Results are shown in Tables 7.34 to 7.37 for each material and for the whole system.

7.8.2 Non-toxicological impacts

The ranking of the different waste management options for CO_2 equivalents stays the same compared to the base scenario, for the whole system as well as for the fractions newspaper and food waste. For PET and the other plastic materials, however, landfilling in this scenario becomes a more favourable choice than incineration. This is due to the large part of the carbon in plastics remaining in the landfill until after the surveyable time period. Only 3% of the carbon in plastics are assumed to be released during ST. The rest of the categories in Table 7.34 keep the same ranking of waste strategies for the whole system, newspaper, PET and food waste. Even though the ranking is kept, in most of the categories the impact values are decreased for the landfilling option. Incineration values are also lowered for some. Due to the exclusion of RT-emissions of phosphorous from sludge landfilled the recycling option is also improved for the aquatic eutrophication (excl NO_x) impact category.

Table 7.34 Weighted results for the impact categories global warming, photo-oxidant formation, acidification (excl SO_x and NO_x), aquatic eutrophication (excl NO_x) and NH_3. The results are in SEK/year. Within each impact category the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	ST Scenario				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Global warming								
Rec dig h/e	-2,4E+08	-4,6E+07	-2,2E+08	-4,6E+06	-2,4E+08	-4,6E+07	-2,2E+08	-4,6E+06
Rec dig f	-2,4E+08	-5,0E+07			-2,4E+08	-5,0E+07		
Rec comp	-1,8E+08	7,2E+06			-1,8E+08	7,2E+06		
Incineration	2,1E+08	8,8E+06	1,0E+07	4,9E+06	2,1E+08	8,8E+06	1,0E+07	4,9E+06
Landfill	4,7E+08	1,4E+08	1,6E+08	3,5E+05	8,5E+08	1,5E+08	2,5E+08	5,3E+06
Photo-oxidant formation max								
Rec dig h/e	-2,0E+08	1,7E+07	-1,7E+07	-3,6E+07	-2,0E+08	1,7E+07	-1,7E+07	-3,6E+07
Rec dig f	-2,1E+08	1,2E+07			-2,0E+08	1,2E+07		
Rec comp	-1,9E+08	2,3E+07			-1,9E+08	2,4E+07		
Incineration	-1,1E+08	-1,2E+07	-3,9E+07	-7,3E+05	-1,1E+08	-1,2E+07	-3,9E+07	-7,3E+05
Landfill	2,5E+08	7,2E+07	8,7E+07	1,8E+05	3,2E+08	7,6E+07	1,2E+08	1,8E+05
Acidification (excl SOx and NOx)								
Rec dig h/e	-2,9E+06	-1,9E+05	-6,3E+05	-5,1E+05	-2,9E+06	-1,9E+05	-6,3E+05	-5,1E+05
Rec dig f	-2,7E+06	5,4E+03			-2,7E+06	5,4E+03		
Rec comp	1,4E+06	4,1E+06			1,4E+06	4,1E+06		
Incineration	-1,2E+06	7,1E+04	-5,3E+05	-9,6E+03	-1,2E+06	8,4E+04	-5,3E+05	-9,6E+03
Landfill	1,3E+05	4,1E+05	-1,6E+05	-2,0E+02	2,0E+05	4,7E+05	-1,6E+05	-2,0E+02
Aquatic eutrophication (excl NOx)								
Rec dig h/e	-5,6E+06	-3,2E+06	3,2E+05	-1,6E+04	-2,3E+06	-3,2E+06	3,2E+05	-1,6E+04
Rec dig f	-5,6E+06	-3,2E+06			-2,3E+06	-3,2E+06		
Rec comp	-2,4E+06	3,8E+04			1,9E+06	1,0E+06		
Incineration	2,4E+06	2,5E+06	-1,8E+05	-3,3E+03	6,5E+07	5,8E+07	-6,0E+04	-3,3E+03
Landfill	2,9E+07	2,5E+07	5,9E+05	6,9E+02	9,5E+07	8,6E+07	6,2E+05	1,4E+03
NH_3 max								
Rec dig h/e	-1,7E+05	-2,2E+05	2,6E+05	2,2E+02	-1,6E+05	-2,2E+05	2,6E+05	2,2E+02
Rec dig f	5,5E+04	2,7E+03			5,8E+04	2,7E+03		
Rec comp	1,6E+07	1,6E+07			1,6E+07	1,6E+07		
Incineration	-4,9E+06	2,1E+05	-2,2E+06	-3,8E+04	-4,8E+06	2,6E+05	-2,2E+06	-3,8E+04
Landfill	1,7E+06	1,9E+06	-2,1E+05	-2,4E+02	1,9E+06	2,1E+06	-2,1E+05	-2,4E+02

7.8.3 Toxicological impacts

Ranking the waste management options with reference to eco-toxicological impacts gives differing results depending on method used. In all three cases the ranking is changed from the base scenario. With the EDIP characterisation method, the whole system is shown to be preferably handled by recycling and secondly by incineration – which is a switch in order compared to the base scenario. Both incineration and recycling, however, get less desirable results than in the base scenario, except for newspaper recycling. In this scenario incineration and recycling are in general losing credit for avoided emissions from ashes from forest residues, but the opposite is true for newspaper recycling, since in the newspaper recycling process forest residues are used for heat production. For incineration, the substance of most importance for this impact category will in the ST scenario be avoided NMVOC, also from the forest residues combustion.

Eco-toxicological impacts from landfilling decreases and increases depending on what fraction that is being considered. The result depends mainly on how much heat that is generated from the collected biogas and the copper content of the waste. A large amount of heat produced gives, in this scenario, a large loss of credited ashes metal emissions and a large copper content gives a large loss of impact due to copper emitted with the leakage during RT compared to the base scenario. When RT-emissions are not accounted for in landfilling the major contributors to the eco-toxicology impact category, using the EDIP method, are dioxins emitted to air during landfill fires and hydrocarbons (C_xH_y) from the loading and packing of waste at the landfill site. Net avoidance of eco-toxicological impacts is recorded for landfilling of food waste. This is due to the large production of biogas, leading to avoidance of electricity production from coal. The substances avoided with most importance are strontium (Sr), selenium (Se), mercury (Hg) and hydrocarbons. These avoided emissions are of sufficient magnitude to overtake the actual emissions mentioned above in this fraction of waste.

Using the USESmin method the rankings of all fractions change. For the whole system this means that landfilling is the most preferable alternative followed by the recycling options. However, for all alternatives for the whole systems, and in most cases also for the three separate fractions, the results are worse than in the base scenario. Incineration has achieved a considerable change for the worse and falls in the ranking for all waste fractions studied. This is, as with the EDIP-characterisation, due to the exclusion of RT-emissions of metals from avoided ashes. But in this case the result will become a net contribution to ecotoxicological impacts for the incineration option. Mercury emissions originating from electricity used in the incineration process being the main contributor. For newspaper and PET, recycling is number one in the ranking followed by landfilling. For food waste landfilling is the most preferable option and incineration second. Digestion and composting are disadvantaged in this impact category, because of the metals in the digestion and compost residue spread on to agricultural land.

With the USESmax method the main change is a switch between incineration and landfilling in the order of preference. In the base scenario the difference is small between these two options with a slight advantage for incineration, except for food waste. Here, landfill overtakes incineration. Landfilling even switches to provide net avoidance of eco-toxicological impacts for the whole system, newspaper and food waste. With the high weighting of toxicological impacts used here landfilling is highly credited for avoidance of electricity from coal via the substances mercury and selenium. Incineration, on the other hand, is disadvantaged by various emissions, mainly from electricity production (selenium to air) and calcium hydroxide production (vanadium to air and water, selenium and barium to water).

Opposite to the USESmin results, no USESmax results are showing larger eco-toxicological impacts in this scenario than in the base scenario.

Food waste management shows a different ranking than the others, using USESmax, with landfilling before incineration before digestion and composting. The digestion and compost residues have a large impact mainly due to nickel and copper emissions to soil.

Table 7.35 Weighted results for eco-toxicological impacts with two characterisation methods, EDIP and USES and two weighting levels minimum and maximum. The figures are in SEK/year. The sub-categories are weighted and added together into eco-toxicological effects (E-tox).

	ST Scenario				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
E-tox EDIP								
Rec dig h/e	-4,7E+06	2,9E+06	-9,1E+05	-1,0E+06	-6,3E+06	2,0E+06	-1,9E+05	-1,1E+06
Rec dig f	-4,7E+06	2,9E+06			-5,4E+06	2,9E+06		
Rec comp	-7,2E+06	3,9E+05			-8,0E+06	3,9E+05		
Incineration	-1,2E+06	-1,1E+05	-4,4E+05	-9,0E+03	-2,2E+07	-2,8E+06	-8,2E+06	-1,1E+05
Landfill	2,2E+05	-2,1E+04	1,2E+05	3,3E+03	3,4E+05	-4,5E+05	4,6E+04	5,4E+04
E-tox USES min								
Rec dig h/e	-6,4E+07	1,3E+08	-1,8E+08	-7,3E+05	-9,0E+07	1,2E+08	-1,7E+08	-7,3E+05
Rec dig f	-2,8E+07	1,7E+08			-4,3E+07	1,7E+08		
Rec comp	-3,8E+07	1,6E+08			-5,4E+07	1,6E+08		
Incineration	2,9E+07	6,8E+06	1,1E+07	1,7E+05	-2,6E+08	-3,2E+07	-9,4E+07	-1,6E+06
Landfill	-7,7E+07	-2,3E+07	-2,7E+07	-2,8E+04	-1,0E+08	-3,1E+07	-3,6E+07	2,2E+04
E-tox USES max								
Rec dig h/e	-3,2E+09	1,5E+09	-1,0E+09	-1,2E+08	-1,2E+09	1,5E+09	-9,9E+08	-1,2E+08
Rec dig f	-3,0E+09	1,8E+09			-1,8E+09	1,9E+09		
Rec comp	-3,1E+09	1,7E+09			-9,3E+08	1,8E+09		
Incineration	9,2E+08	1,4E+08	3,8E+08	4,8E+06	1,6E+10	2,2E+09	5,6E+09	1,8E+08
Landfill	-3,7E+08	-1,2E+08	-1,3E+08	1,6E+05	1,6E+10	2,1E+09	5,7E+09	1,9E+08

No major differences in human toxicological impacts are resulting when comparing this scenario with the base scenario and no changes in ranking occur. The larger differences are seen when the EDIP method is used. Recycling is then slightly better off in this scenario, looking at the whole system. The result for PET is not changed, newspaper recycling is better off here, since the energy generation in the newspaper recycling process is partly from forest residues and metal RT-emissions from the ashes are excluded in this scenario. Food waste digestion with heat recovery, on the other hand, loses the credit for the same emissions being avoided.

With the EDIP method incineration has lower human toxicological impact in the base scenario considering the whole system, as well as the three fractions separately. The main contributors to this impact category for incineration is in the ST scenario avoided NMVOC from the avoided heat production. Major emissions, which are excluded as they occur during RT, are emissions of dioxins from landfilled waste ashes and avoided emissions of arsenic from forest residues ashes. The latter of a greater magnitude.

The major contributors to this impact category with the EDIP-characterisation for landfilling are in this scenario, avoided mercury emissions from avoided electricity generation and, of lower magnitude, emissions of hydrocarbons from compaction at the landfill. Generally, the landfill option has less human toxicological impact in the base scenario. The main emissions that have been excluded in this scenario are emissions of mercury and lead with the leakage water and avoided emissions of arsenic from the forest residues ashes. As for incineration the latter of higher magnitude. Plastics, with PET as the example, show a different result, with less human toxicological impact in the ST scenario. This is because less landfill gas is produced from plastics as the degradation is slower, and thus less heat production from forest residues is avoided.

With the USES methods the main human toxicological impacts in the base scenario are from emissions not affected by the RT-discussion and the changes are thus small. The largest difference is seen for incineration of food waste with USESmin. This is due to the dioxins emitted from landfilling of the food waste ashes, which are excluded. Food waste is the only waste fraction for which dioxins are part of the composition (see Table 4.4).

Table 7.36 Weighted results for human toxicological impacts with two characterisation methods, EDIP and USES and two weighting levels, minimum and maximum. The figures are in SEK/year. The sub-categories are weighted and added together into toxicological effects on human health (H-tox).

	ST Scenario				Base scenario			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
H-tox EDIP								
Rec dig h/e	-7,3E+08	-2,7E+06	-2,5E+08	-8,4E+07	-7,5E+08	-1,3E+07	-2,4E+08	-8,4E+07
Rec dig f	-7,0E+08	3,2E+07			-7,0E+08	3,2E+07		
Rec comp	-6,9E+08	3,9E+07			-6,9E+08	3,9E+07		
Incineration	-9,0E+07	-7,6E+06	-3,2E+07	-6,7E+05	-3,1E+08	-3,5E+07	-1,1E+08	-1,8E+06
Landfill	-8,0E+07	-2,8E+07	-2,6E+07	1,5E+05	-9,1E+07	-3,5E+07	-3,4E+07	5,6E+05
H-tox USES min								
Rec dig h/e	-2,0E+07	1,3E+06	-1,2E+06	-3,5E+06	-2,0E+07	1,3E+06	-1,1E+06	-3,5E+06
Rec dig f	-2,0E+07	9,6E+05			-2,0E+07	9,6E+05		
Rec comp	-1,9E+07	1,7E+06			-1,9E+07	1,7E+06		
Incineration	-3,9E+06	-6,7E+05	-1,4E+06	-2,8E+04	-3,9E+06	-3,6E+05	-1,4E+06	-2,8E+04
Landfill	6,6E+05	3,5E+04	3,1E+05	6,9E+03	6,6E+05	3,2E+04	3,1E+05	7,1E+03
H-tox USES max								
Rec dig h/e	-4,4E+09	2,9E+08	-2,6E+08	-8,0E+08	-4,4E+09	2,9E+08	-2,6E+08	-8,0E+08
Rec dig f	-4,5E+09	2,2E+08			-4,5E+09	2,2E+08		
Rec comp	-4,3E+09	3,9E+08			-4,3E+09	3,9E+08		
Incineration	-8,9E+08	-8,3E+07	-3,2E+08	-6,3E+06	-8,9E+08	-8,2E+07	-3,1E+08	-6,3E+06
Landfill	1,5E+08	8,0E+06	7,0E+07	1,6E+06	1,5E+08	7,3E+06	6,9E+07	1,6E+06

7.8.4 Total weighted results

Totally, recycling is least affected by the changes of this scenario. Landfill gains credit and incineration loses or gains depending on method used. For landfill the impact categories that are highest weighted are with Ecotax 98/EDIP, abiotic resources, global warming and photo-oxidant formation, for incineration and the recycling options, the same with the addition of human toxicological impacts. The only change in ranking compared to the base scenario with the EDIP method is for PET, where the preference becomes recycling before landfilling before incineration.

In the Ecotax 98/USESmin method abiotic resources and photo-oxidant formation are lower weighted and toxicological impacts are differently characterised and weighted compared to the Ecotax 98/EDIP method. The most important impact category for the whole system is in this case global warming. Changes in the order of the ranking of the waste management options occur for PET and food waste. For PET, the same result as in Ecotax 98/EDIP is achieved. The difference for food waste is that in this scenario landfill is ranked as third, before digestion with biogas used for bus-fuel and composting.

More alterations in ranking occur if the Ecotax 98/USESmax method is used. Abiotic resources, global warming, photo-oxidant formation and both ecological and human toxicological impacts are major contributors to the total weighted results for the whole system for all waste management options. The switches in ranking order makes recycling preferred before landfilling before incineration for the whole system, newspaper and PET. The order for food waste is landfilling, incineration, digestion and last composting.

Overall, a change in ranking of waste management options for the whole system occurs only for the category eco-toxicological impacts comparing the ST scenario with the base scenario. For the three fractions studied separately, changes in ranking occur in that category as well, adding global warming for PET and human toxicological impacts for food waste.

With the weighting method Eco-indicator 99 ranking results are altered in the favour of landfilling both for PET and food waste. For the PET fraction the order of ranking becomes recycling, landfill, incineration. Landfill is favoured since the emissions of greenhouse gases occurring during RT are omitted, and for plastics this is the major part. Incineration of plastics leads to direct emissions of the whole fossil carbon content, as CO_2.

Table 7.37 Total weighted results with two different characterisation methods for toxicological impacts, EDIP and USES, and two weighting levels within the Ecotax 98 weighting method, minimum and maximum. The figures for the Ecotax 98 results are in SEK/year. In addition, results weighted with the Eco-indicator 99 are presented, these are in points/year.

	ST Scenario				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Total Ecotax 98/ EDIP								
Rec dig h/e	-3,4E+09	-2,3E+08	-1,6E+09	-2,0E+08	-3,4E+09	-2,4E+08	-1,6E+09	-2,0E+08
Rec dig f	-3,4E+09	-1,7E+08			-3,4E+09	-1,7E+08		
Rec comp	-3,1E+09	1,6E+08			-3,1E+09	1,6E+08		
Incineration	8,1E+07	1,0E+07	-1,5E+07	3,4E+06	-9,4E+07	3,6E+07	-1,0E+08	2,2E+06
Landfill	2,6E+08	8,4E+07	8,3E+07	7,6E+05	7,6E+08	1,5E+08	1,9E+08	6,1E+06
Total Ecotax 98/ USES min								
Rec dig h/e	-5,1E+08	7,8E+07	-5,0E+08	-2,5E+07	-5,3E+08	6,8E+07	-4,9E+08	-2,5E+07
Rec dig f	-4,3E+08	1,6E+08			-4,4E+08	1,6E+08		
Rec comp	-4,1E+08	1,8E+08			-4,2E+08	1,8E+08		
Incineration	2,3E+08	1,0E+07	3,0E+07	4,8E+06	6,7E+06	3,4E+07	-7,4E+07	3,0E+06
Landfill	4,4E+08	1,5E+08	1,4E+08	3,9E+05	8,7E+08	2,1E+08	2,2E+08	5,4E+06
Total Ecotax 98/ USES max								
Rec dig h/e	-1,0E+10	1,6E+09	-2,7E+09	-1,0E+09	-8,3E+09	1,5E+09	-2,6E+09	-1,0E+09
Rec dig f	-1,0E+10	1,8E+09			-8,1E+09	1,8E+09		
Rec comp	-9,8E+09	2,2E+09			-7,6E+09	2,3E+09		
Incineration	2,0E+08	7,5E+07	7,7E+07	2,7E+06	1,5E+10	2,2E+09	5,3E+09	1,8E+08
Landfill	1,2E+08	2,4E+06	5,0E+07	2,3E+06	1,7E+10	2,3E+09	6,0E+09	2,0E+08
Total Eco-indicator 99								
Rec dig h/e	-5,9E+07	1,7E+07	-1,3E+07	-3,2E+06	-5,3E+07	1,6E+07	-1,2E+07	-3,2E+06
Rec dig f	-6,1E+07	1,5E+07			-5,3E+07	1,5E+07		
Rec comp	-5,6E+07	2,0E+07			-4,8E+07	2,0E+07		
Incineration	1,7E+06	1,8E+05	6,7E+05	4,7E+04	6,0E+07	1,3E+07	1,8E+07	5,5E+05
Landfill	7,2E+06	2,0E+06	2,5E+06	1,4E+04	1,0E+08	1,8E+07	3,2E+07	8,1E+05

For food waste landfilling is ranked as number two, using Eco-indicator 99, subsequent to incineration. The digestion and composting options are not much favoured by the exclusion of RT-emissions since the chromium content of the waste, which is the emission highest weighted, in these cases are modelled as direct emissions to soil, as the residues are spread on to agricultural land. For the other two options most of the chromium is omitted since it is assumed to be part of the RT-leachate from waste and ash landfills.

7.8.5 Summary

A final summary of the ranking of the waste management options for the whole system is given in Table 7.38.

Table 7.38 The ranking of the waste management options for the whole system for each impact category affected in this scenario. When the three recycling alternatives are ranked in a sequence they are reported as one. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling

Impact category	Ranking						
Global warming	Rec	<	Inc	<	Lf		
Photo-oxidant formation max	Rec	<	Inc	<	Lf		
Acidification (excl SO_x and NO_x)	Rec/d	<	Inc	<	Lf	<	Rec/c
Aquatic eutrophication (excl NO_x)	Rec	<	Inc	<	Lf		
NH_3 max	Inc	<	Rec/d	<	Lf	<	Rec/c
E-tox EDIP	Rec	<	Inc	<	Lf		
E-tox USESmin	Lf	<	Rec	<	Inc		
E-tox USESmax	Rec	<	Lf	<	Inc		
H-tox EDIP	Rec	<	Inc	<	Lf		
H-tox USESmin	Rec	<	Inc	<	Lf		
H-tox USESmax	Rec	<	Inc	<	Lf		
Ecotax 98/EDIP	Rec	<	Inc	<	Lf		
Ecotax 98/USESmin	Rec	<	Inc	<	Lf		
Ecotax 98/USESmax	Rec	<	Lf	<	Inc		
Eco-indicator 99	Rec	<	Inc	<	Lf		

7.9 Results Scenario ST + Carbon sink

Applying the carbon sink concept to the ST scenario leads to some additional changes in the ranking of waste management options. Global warming, the cause for discussing carbon sinks, is the only impact category affected by adding this assumption. Waste fractions affected are the ones containing biological carbon.

7.9.1 Global warming

In this scenario the ranking of waste management options will be recycling before landfilling before incineration for global warming for the whole system and for newspaper as can be seen in Table 7.39. This is a change compared to the ST scenario, in some cases. For food waste it is, however, still more preferable, considering greenhouse gas emissions, to incinerate than to landfill. This is because the amount of carbon left within the landfill until RT is rather small for food waste. Still, the digestion and composting alternatives are the most preferable.

For corrugated cardboard it is also still a better option, from a global warming perspective to incinerate than to landfill. The difference between this paper fraction and the other two may be a consequence of the material composition, where a larger part of the carbon in corrugated cardboard is assumed to be degraded during ST.

Table 7.39 Weighted global warming results for the different waste management options for the base scenario, the ST scenario and the ST scenario - assuming landfill as a carbon sink. The results are in SEK/year. The results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor.

	ST + carbon sink Scenario		
	Whole system	Food waste	Newspaper
Global warming			
Rec dig h/e	-2,4E+08	-4,6E+07	-2,2E+08
Rec dig f	-2,4E+08	-5,0E+07	
Rec comp	-1,8E+08	7,2E+06	
Incineration	2,1E+08	8,8E+06	1,0E+07
Landfill	2,0E+08	1,2E+08	6,0E+06

	ST Scenario		
	Whole system	Food waste	Newspaper
Global warming			
Rec dig h/e	-2,4E+08	-4,6E+07	-2,2E+08
Rec dig f	-2,4E+08	-5,0E+07	
Rec comp	-1,8E+08	7,2E+06	
Incineration	2,1E+08	8,8E+06	1,0E+07
Landfill	4,7E+08	1,4E+08	1,6E+08

	Base Scenario		
	Whole system	Food waste	Newspaper
Global warming			
Rec dig h/e	-2,4E+08	-4,6E+07	-2,2E+08
Rec dig f	-2,4E+08	-5,0E+07	
Rec comp	-1,8E+08	7,2E+06	
Incineration	2,1E+08	8,8E+06	1,0E+07
Landfill	8,5E+08	1,5E+08	2,5E+08

7.9.2 Total weighted results

Totally, the ranking changes for the whole system and for newspaper when the landfill is handled as a carbon sink. Landfill switches place with incineration and becomes the second best option when Ecotax 98/EDIP or Ecotax 98/USESmin are used giving the ranking order: recycling before landfilling before incineration. For Ecotax 98/USESmax, this was the ranking order also in the ST scenario. The total ranking for food waste is not changed, independent of method used.

With Eco-indicator 99 the order of ranking is only changed for newspaper, where landfill becomes a better option than incineration, while recycling is still the best option.

Table 7.40 Total weighted results with two different characterisation methods for toxicological impacts, EDIP and USES and two weighting levels within the Ecotax 98 weighting method, minimum and maximum. The figures for the Ecotax 98 results are in SEK/year. Results weighted with the Eco-indicator 99 are presented in points/year.

	ST + carbon sink Scenario			**ST Scenario**			**Base scenario**		
	Whole system	Food waste	Newspaper	Whole system	Food waste	Newspaper	Whole system	Food waste	Newspaper
Total Ecotax 98/ EDIP max									
Rec dig h/e	-3,4E+09	-2,3E+08	-1,6E+09	-3,4E+09	-2,3E+08	-1,6E+09	-3,4E+09	-2,4E+08	-1,6E+09
Rec dig f	-3,4E+09	-1,7E+08		-3,4E+09	-1,7E+08		-3,4E+09	-1,7E+08	
Rec comp	-3,1E+09	1,6E+08		-3,1E+09	1,6E+08		-3,1E+09	1,6E+08	
Incineration	8,1E+07	1,0E+07	-1,5E+07	8,1E+07	1,0E+07	-1,5E+07	-9,4E+07	3,6E+07	-1,0E+08
Landfill	-4,5E+06	6,9E+07	-7,2E+07	2,6E+08	8,4E+07	8,3E+07	7,6E+08	1,5E+08	1,9E+08
Total Ecotax 98/ USES min									
Rec dig h/e	-5,1E+08	7,8E+07	-5,0E+08	-5,1E+08	7,8E+07	-5,0E+08	-5,3E+08	6,8E+07	-4,9E+08
Rec dig f	-4,3E+08	1,6E+08		-4,3E+08	1,6E+08		-4,4E+08	1,6E+08	
Rec comp	-4,1E+08	1,8E+08		-4,1E+08	1,8E+08		-4,2E+08	1,8E+08	
Incineration	2,3E+08	1,5E+07	3,0E+07	2,3E+08	1,5E+07	3,0E+07	6,7E+06	3,4E+07	-7,4E+07
Landfill	1,8E+08	1,3E+08	-1,3E+07	4,4E+08	1,5E+08	1,4E+08	8,7E+08	2,1E+08	2,2E+08
Total Ecotax 98/ USES max									
Rec dig h/e	-1,0E+10	1,6E+09	-2,7E+09	-1,0E+10	1,6E+09	-2,7E+09	-8,3E+09	1,5E+09	-2,6E+09
Rec dig f	-1,0E+10	1,8E+09		-1,0E+10	1,8E+09		-8,1E+09	1,8E+09	
Rec comp	-9,8E+09	2,2E+09		-9,8E+09	2,2E+09		-7,6E+09	2,3E+09	
Incineration	2,0E+08	7,5E+07	7,7E+07	2,0E+08	7,5E+07	7,7E+07	1,5E+10	2,2E+09	5,3E+09
Landfill	-1,5E+08	-1,2E+07	-1,1E+08	1,2E+08	2,4E+06	5,0E+07	1,7E+10	2,3E+09	6,0E+09
Total Eco-indicator 99									
Rec dig h/e	-5,9E+07	1,7E+07	-1,3E+07	-5,9E+07	1,7E+07	-1,3E+07	-5,3E+07	1,6E+07	-1,2E+07
Rec dig f	-6,1E+07	1,5E+07		-6,1E+07	1,5E+07	-1,3E+07	-5,3E+07	1,5E+07	
Rec comp	-5,6E+07	2,0E+07		-5,6E+07	2,0E+07	-1,3E+07	-4,8E+07	2,0E+07	
Incineration	1,7E+06	1,8E+05	6,7E+05	1,7E+06	1,8E+05	6,7E+05	6,0E+07	1,3E+07	1,8E+07
Landfill	3,2E+06	1,8E+06	2,0E+05	7,2E+06	2,0E+06	2,5E+06	1,0E+08	1,8E+07	3,2E+07

7.9.3 Summary

A final summary of the ranking of the waste management options for the whole system is given in Table 7.41.

Table 7.41 The ranking of the waste management options for the whole system for global warming and total weighted results. When the three recycling alternatives are close these are reported as one. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling.

Impact category	**Ranking**				
Global warming	Rec	<	Lf	<	Inc
Ecotax 98/ EDIP	Rec	<	Lf	<	Inc
Ecotax 98/ USESmin	Rec	<	Lf	<	Inc
Ecotax 98/ USESmax	Rec	<	Lf	<	Inc
Eco-indicator 99	Rec	<	Inc	<	Lf

7.10 Results Scenario Plastic Palisade

7.10.1 Introduction

The results for the scenario plastic palisade are presented for the plastic fraction as a total. The whole system is not considered here, but the result for the whole system is presented in Appendix 4. The only difference compared to the base scenario for the plastics fractions is that one extra mode of recycling plastics is added. This option is here called mixed recycling as opposed to recycling of fractions separately. Weighted results for each impact category and total weighted results for each treatment option is presented in Table 7.42.

Table 7.42 Weighted results for the different impact categories and total weighted results for the different waste management options for a total of all the plastic fractions studied. The two categories for energy are presented in MJ/year and the others in SEK/year, except for the results received when using the Eco-indicator 99, which is in points/year.

	Landfill	Incineration	Recycling	Mixed Recycling
Total energy	-7,1E+07	-5,5E+09	-7,7E+09	-4,7E+09
Non-renewable energy	-2,1E+07	-5,6E+07	-6,1E+09	7,7E+08
Abiotic resources	-2,9E+06	-7,2E+06	-8,6E+08	1,1+E8
Non-treated waste	-2,6E+05	5,6E+06	5,0E+05	2,7E+06
Global warming	1,7E+08	1,6E+08	2,6E+07	1,9E+08
Photo-oxidant formation max	7,0E+06	-2,9E+07	-2,0E+08	-1,8E+07
Acidification (excl SO_x and NO_x)	-9,0E+03	-3,7E+05	-1,3E+06	-1,7E+05
Aquatic eutrophication (excl NO_x)	4,3E+04	1,6E+06	3,3E+06	2,2E+06
SO_x	9,9E+04	-3,2E+06	-9,3E+06	-1,4E+06
NO_x	1,1E+06	-5,0E+06	-3,0E+07	-8,1E+04
NH_3 max	-1,3E+04	-1,5E+06	-3,7E+05	-9,8E+05
E-tox EDIP	1,3E+06	-4,9E+06	-7,8E+06	-7,4E+06
E-tox USES min	-3,7E+05	-6,5E+07	-3,6E+06	-1,4E+08
E-tox USES max	4,7E+09	4,4E+09	5,3E+08	-8,1E+08
H-tox EDIP	1,3E+07	-8,1E+07	-4,6E+08	-1,3E+07
H-tox USES min	1,7E+05	-1,2E+06	-2,0E+07	-8,0E+05
H-tox USES max	3,8E+07	-2,6E+08	-4,4E+09	-1,8E+08
Total Ecotax 98/EDIP	2,0E+08	2,7E+07	-1,6E+09	2,7E+08
Total Ecotax 98/USES min	1,7E+08	8,2E+07	-5,4E+07	5,6E+07
Total Ecotax 98/USES max	4,9E+09	4,2E+09	-4,9E+09	-7,1E+08
Total Eco-indicator 99	1,0E+08	6,0E+07	-5,2E+07	1,3E+07

7.10.2 Energy, abiotic resources and non-treated waste

Energetically, mixed recycling is ranked third, incineration having a slightly better energy balance and landfilling being worse. For the non-renewable part of the energy, mixed recycling is the least preferred option. Opposite to the other alternatives mixed recycling results in a net consumption of non-renewable energy. The abiotic resources used are mainly the same as the non-renewable energy resources and this impact category consequently shows the same ranking.

Rough calculations of the possibility of one plastic palisade replacing four wooden palisades, due to longer life time, indicates that no major differences in the results for the impact categories energy and global warming will occur. In the category non-renewable energy mixed recycling may climb in the ranking if different lifetimes are assumed. In this study no exact calculations concerning this is performed.

Mixed recycling has a positive net figure for non-treated waste. This is mainly bulk waste from the electricity production process. Incineration has a higher figure.

7.10.3 Non-toxicological impacts

Since the mixed recycling process involves large amounts of electricity produced from hard coal the ranking for the category global warming puts this option as last alternative of the four choices. The difference between incineration, landfilling and mixed recycling is small. This is explained by the fact that the heat production avoided in the incineration case is produced from renewable resources and thus fossil carbon dioxide is charged and biological carbon dioxide is credited for the incineration option.

For most of the other non-toxicological impact categories presented in Table 7.42 mixed recycling is ranked as third best option, only better off than landfilling.

7.10.4 Toxicological impacts

From a toxicological point of view mixed recycling seems more desirable. Considering eco-toxicological impacts mixed recycling is ranked as the most preferred alternative using the USES methods and as the second most preferred alternative if the EDIP method is used for characterisation. This is mainly due to the fact that emissions of copper from the impregnated wood are avoided.

Considering human toxicological impacts mixed recycling does not have the same advantage. Here, the ranking is separate recycling before incineration before mixed recycling, with landfilling last. Avoided NMVOC from heat production represents a main part of the total result for mixed recycling. After use the palisades made from the recycled plastics are assumed to be incinerated with heat recovery.

7.10.5 Total weighted results

Totally, the result depends on which characterisation method that is used for the toxicological impacts. Using Ecotax 98/EDIP, mixed recycling is ranked as the last choice for management of plastic waste. But with the Ecotax 98/USES methods it is ranked second after separate recycling. The major shares of the totals for mixed recycling are from the categories global warming and eco-toxicological impacts. With Ecotax 98/USESmax human toxicology is a third major impact category.

7.10.6 Summary

To sum this up, mixed recycling as modelled in this study demands a large amount of electricity, which makes this alternative undesirable considering energy balance and global warming. The other major category, eco-toxicological impacts, shows that the avoidance of emissions from chemicals in the wood preservative may also be important.

A final summary of the ranking of the waste management options for plastics in the scenario where recycled mixed plastics is used for palisades, replacing impregnated wood is presented in Table 7.43.

Table 7.43 The ranking of the waste management options for the aggregated plastics waste fractions for each impact category. Rec means the separate recycling of plastic fractions, replacing virgin material of the same kind. Mix is the mixed plastic recycling, Inc is incineration and Lf landfilling.

Impact category	**Ranking**						
Total energy	Rec	<	Inc	<	Mix	<	Lf
Non-renewable energy	Rec	<	Inc	<	Lf	<	Mix
Abiotic resources	Rec	<	Inc	<	Lf	<	Mix
Non-treated waste	Lf	<	Rec	<	Mix	<	Inc
Global warming	Rec	<	Inc	<	Lf	<	Mix
Photo-oxidant formation max	Rec	<	Inc	<	Mix	<	Lf
Acidification (excl SO_x and NO_x)	Rec	<	Inc	<	Mix	<	Lf
Aquatic eutrophication (excl NO_x)	Lf	<	Inc	<	Mix	<	Rec
SO_x	Rec	<	Inc	<	Mix	<	Lf
NO_x	Rec	<	Inc	<	Mix	<	Lf
NH_3 max	Inc	<	Mix	<	Rec	<	Lf
E-tox EDIP	Rec	<	Mix	<	Inc	<	Lf
E-tox USESmin	Mix	<	Inc	<	Rec	<	Lf
E-tox USESmax	Mix	<	Rec	<	Inc	<	Lf
H-tox EDIP	Rec	<	Inc	<	Mix	<	Lf
H-tox USESmin	Rec	<	Inc	<	Mix	<	Lf
H-tox USESmax	Rec	<	Inc/Mix	<	Lf		
Ecotax 98/EDIP	Rec	<	Inc	<	Lf	<	Mix
Ecotax 98/USESmin	Rec	<	Mix	<	Inc	<	Lf
Ecotax 98/USESmax	Rec	<	Mix	<	Inc	<	Lf
Eco-indicator 99	Rec	<	Mix	<	Inc	<	Lf

7.11 Results Scenario Excluding metals in ashes from biofuels

7.11.1 Introduction

The importance of the impacts of metals in the ashes resulting from heat production of forest residues is analysed in this scenario. The base scenario’s avoided heat production from forest residues includes an assumed retrieval of generated ashes to the forest. Ashes can be characterised by nutrient content, trace elements and metals. In this study the metals arsenic (As), bohr (B), cadmium (Cd), chromium (Cr), copper (Cu), mercury (Hg), nickel (Ni), lead (Pb) and zinc (Zn) are included. These metals are in the base scenario modelled to be completely emitted to soil according to the hypothetical infinite time perspective (described in chapter 2). In this scenario, these metals are excluded assuming that the ashes are spread over the same area as where the outtake of biomass occurred.

The general difference compared to the base scenario, when excluding metals, is that the avoided impact of the avoided heat production decreases. The treatment options where heat production is a function (Table 7.44), are less favoured in this scenario compared to the base scenario. This is reflected in the results, especially for incineration, to some extent for landfilling and digestion and to a smaller extent for recycling. This is consequent to the different amounts of heat generated from the different treatment strategies. In the case of material recycling (for mixed cardboard, PE, PP, PS and PVC) some reject is assumed to be incinerated with heat recovery.

Table 7.44 Treatment options and waste materials included in the study where heat production is a function.

Treatment options with the function heat production	**Waste materials**
Recycling combined with composting	Mixed cardboard, PE, PP, PS and PVC
Recycling combined with digestion (h/e)	Food waste, mixed cardboard, PE, PP, PS and PVC
Recycling combined with digestion (f)	Mixed cardboard, PE, PP, PS and PVC
Incineration	All
Landfilling	All

Impact categories that have a major contribution to the total result for the forest residues heat production process when excluding metals are for the Ecotax 98/EDIP method photo-oxidant formation (CO, NMVOC) followed by abiotic resources (crude oil). For the Ecotax 98/USESmax method it is mainly human toxicology - emission to air (NMVOC) and for Ecotax 98/USESmin it is greenhouse gases (CO_2 and N_2O) and NO_x. The main contributors to the total result for the Eco-indicator 99 method are human health - respiratory inorganics (NO_x and SO_x) and resources - fossil fuels (crude oil).

Compared to the base scenario, the exclusion of the metals affects only the impact categories eco-toxicology, human toxicology, and in a very small extent the total weighted results. The results of these are presented in Tables 7.45-7.47.

7.11.2 Toxicological impacts

In the category eco-toxicology, incineration is in general less favoured compared to the base scenario. For the EDIP method the recycling alternatives are the most preferable for newspaper, PET and the whole system. Incineration is the second option in ranking but the difference to landfill has decreased notably. The ranking for food waste is unchanged.

With the USESmin method, landfilling and recycling combined with digestion or composting are better than incineration for the whole system, newspaper and PET. The ranking for food waste is landfilling before incineration before the digestion and composting options. In the USESmax method the ranking is in general the same as in the base scenario.

Table 7.45 Weighted results for eco-toxicological impacts with two characterisation methods, EDIP and USES and two weighting levels minimum and maximum. The figures are in SEK/year. The sub-categories are weighted and added together into eco-toxicological effects (E-tox).

	Scenario Excluding metals in ashes				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
E-tox EDIPmax								
Rec dig h/e	-3.3E+06	2.9E+06	-1.9E+05	-1.1E+06	-6,3E+06	2,0E+06	-1,9E+05	-1,1E+06
Rec dig f	-3.3E+06	2.9E+06			-5,4E+06	2,9E+06		
Rec comp	-5.8E+06	3.9E+05			-8,0E+06	3,9E+05		
Incineration	1.7E+06	2.4E+05	4.7E+05	4.4E+04	-2,2E+07	-2,8E+06	-8,2E+06	-1,1E+05
Landfill	2.9E+06	2.9E+05	9.1E+05	5.5E+04	3,4E+05	-4,5E+05	4,6E+04	5,4E+04
E-tox USESmin								
Rec dig h/e	-5.3E+07	1.3E+08	-1.7E+08	-7.3E+05	-9,0E+07	1,2E+08	-1,7E+08	-7,3E+05
Rec dig f	-1.7E+07	1.7E+08			-4,3E+07	1,7E+08		
Rec comp	-2.8E+07	1.6E+08			-5,4E+07	1,6E+08		
Incineration	3.5E+07	4.9E+06	1.2E+07	2.3E+05	-2,6E+08	-3,2E+07	-9,4E+07	-1,6E+06
Landfill	-7.1E+07	-2.2E+07	-2.6E+07	3.6E+04	-1,0E+08	-3,1E+07	-3,6E+07	2,2E+04
E-tox USESmax								
Rec dig h/e	-9.7E+08	1.5E+09	-9.9E+08	-1.2E+08	-1,2E+09	1,5E+09	-9,9E+08	-1,2E+08
Rec dig f	-7.7E+08	1.7E+09			-1,8E+09	1,9E+09		
Rec comp	-7.6E+08	1.8E+09			-9,3E+08	1,8E+09		
Incineration	1.8E+10	2.4E+09	6.3E+09	1.9E+08	1,6E+10	2,2E+09	5,6E+09	1,8E+08
Landfill	1.6E+10	2.2E+09	5.8E+09	1.9E+08	1,6E+10	2,1E+09	5,7E+09	1,9E+08

In category human toxicology there are no changes in ranking with the USES methods. For the EDIP method, the recycling alternatives are still the most preferred options for the whole system, but landfill becomes second best in this scenario.

Table 7.46 Weighted results for human toxicological impacts with two characterisation methods, EDIP and USES and two weighting levels, minimum and maximum. The figures are in SEK/year. The sub-categories are weighted and added together into human toxicological effects (H-tox).

	Scenario Excluding metals in ashes				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
H-tox EDIP								
Rec dig h/e	-7.1E+08	-2.7E+06	-2.4E+08	-8.4E+07	-7,5E+08	-1,3E+07	-2,4E+08	-8,4E+07
Rec dig f	-6.7E+08	3.2E+07			-7,0E+08	3,2E+07		
Rec comp	-6.7E+08	3.9E+07			-6,9E+08	3,9E+07		
Incineration	-3.0E+07	1.4E+05	-1.2E+07	-4.5E+04	-3,1E+08	-3,5E+07	-1,1E+08	-1,8E+06
Landfill	-6.3E+07	-2.7E+07	-2.4E+07	5.7E+05	-9,1E+07	-3,5E+07	-3,4E+07	5,6E+05
H-tox USES min								
Rec dig h/e	-2.0E+07	1.3E+06	-1.1E+06	-3.5E+06	-2,0E+07	1,3E+06	-1,1E+06	-3,5E+06
Rec dig f	-2.0E+07	9.6E+05			-2,0E+07	9,6E+05		
Rec comp	-1.9E+07	1.7E+06			-1,9E+07	1,7E+06		
Incineration	-3.7E+06	-3.4E+05	-1.3E+06	-2.7E+04	-3,9E+06	-3,6E+05	-1,4E+06	-2,8E+04
Landfill	6.8E+05	3.8E+04	3.1E+05	7.1E+03	6,6E+05	3,2E+04	3,1E+05	7,1E+03
H-tox USES max								
Rec dig h/e	-4.4E+09	2.9E+08	-2.6E+08	-8.0E+08	-4,4E+09	2,9E+08	-2,6E+08	-8,0E+08
Rec dig f	-4.5E+09	2.2E+08			-4,5E+09	2,2E+08		
Rec comp	-4.3E+09	3.9E+08			-4,3E+09	3,9E+08		
Incineration	-8.5E+08	-7.7E+07	-3.0E+08	-6.1E+06	-8,9E+08	-8,2E+07	-3,1E+08	-6,3E+06
Landfill	1.5E+08	8.5E+06	7.1E+07	1.6E+06	1,5E+08	7,3E+06	6,9E+07	1,6E+06

7.11.3 Total weighted results

In general there are no changes in hierarchy for the total weighted results compared to the base scenario. Also here the difference between incineration and landfilling decreases

Table 7.47 Total weighted results with two different characterisation methods for toxicological impacts EDIP and USES and two weighting levels within the Ecotax 98 weighting method, minimum and maximum. The figures for the Ecotax 98 results are in SEK/year. In addition results weighted with the Eco-indicator 99 are presented, these are in points/year.

	Scenario Excluding metals in ashes				**Base scenario**			
	Whole system	Food waste	Newspaper	PET	Whole system	Food waste	Newspaper	PET
Total Ecotax 98/EDIP								
Rec dig h/e	-3.4E+09	-2.3E+08	-1.6E+09	-2.0E+08	-3,4E+09	-2,4E+08	-1,6E+09	-2,0E+08
Rec dig f	-3.4E+09	-1.7E+08			-3,4E+09	-1,7E+08		
Rec comp	-3.0E+09	1.6E+08			-3,1E+09	1,6E+08		
Incineration	2.1E+08	7.4E+07	5.6E+06	4.1E+06	-9,4E+07	3,6E+07	-1,0E+08	2,2E+06
Landfill	7.9E+08	1.6E+08	2.0E+08	6.1E+06	7,6E+08	1,5E+08	1,9E+08	6,1E+06
Total Ecotax 98/USES min								
Rec dig h/e	-5.0E+08	7.8E+07	-4.9E+08	-2.5E+07	-5,3E+08	6,8E+07	-4,9E+08	-2,5E+07
Rec dig f	-4.2E+08	1.6E+08			-4,4E+08	1,6E+08		
Rec comp	-3.9E+08	1.8E+08			-4,2E+08	1,8E+08		
Incineration	3.0E+08	7.1E+07	3.2E+07	4.9E+06	6,7E+06	3,4E+07	-7,4E+07	3,0E+06
Landfill	9.0E+08	2.2E+08	2.3E+08	5.4E+06	8,7E+08	2,1E+08	2,2E+08	5,4E+06
Total Ecotax 98/USES max								
Rec dig h/e	-8.1E+09	1.6E+09	-2.6E+09	-1.0E+09	-8,3E+09	1,5E+09	-2,6E+09	-1,0E+09
Rec dig f	-7.9E+09	1.8E+09			-8,1E+09	1,8E+09		
Rec comp	-7.4E+09	2.3E+09			-7,6E+09	2,3E+09		
Incineration	1.7E+10	2.4E+09	6.0E+09	1.9E+08	1,5E+10	2,2E+09	5,3E+09	1,8E+08
Landfill	1.7E+10	2.4E+09	6.1E+09	2.0E+08	1,7E+10	2,3E+09	6,0E+09	2,0E+08
Total Eco-indicator 99								
Rec dig h/e	-4.8E+07	1.7E+07	-1.2E+07	-3.2E+06	-5,25E+07	1,57E+07	-1,16E+07	-3,18E+06
Rec dig f	-5.0E+07	1.5E+07			-5,32E+07	1,49E+07		
Rec comp	-4.5E+07	2.0E+07			-4,80E+07	2,02E+07		
Incineration	9.7E+07	1.7E+07	3.1E+07	7.8E+05	6,03E+07	1,28E+07	1,79E+07	5,52E+05
Landfill	1.1E+08	1.9E+07	3.3E+07	8.2E+05	1,02E+08	1,81E+07	3,19E+07	8,13E+05

7.11.4 Summary

A final summary of the ranking of the waste management options for the whole system, in the scenario where metals in forest residues ashes are not modelled as emissions to soil is given in Table 7.48.

Table 7.48 The ranking of the waste management options for the whole system for toxicological impact categories. When the three recycling alternatives are ranked in a row they are reported here as one. Rec/d is the recycling alternative where food waste is anaerobically digested, this alternative may be split in (he) where heat and electricity is generated from the biogas collected and (f) where the biogas is used for fuelling buses. Rec/c is recycling combined with composting, Inc is incineration and Lf landfilling.

Impact category	**Ranking**				
E-tox EDIP	Rec	<	Inc	<	Lf
E-tox USESmin	Inc	<	Rec	<	Lf
E-tox USESmax	Rec	<	Lf	<	Inc
H-tox EDIP	Rec	<	Lf	<	Inc
H-tox USESmin	Rec	<	Inc	<	Lf
H-tox USESmax	Rec	<	Inc	<	Lf
Ecotax 98/ EDIP	Rec	<	Inc	<	Lf
Ecotax 98/ USESmin	Rec	<	Inc	<	Lf
Ecotax 98/ USESmax	Rec	<	Inc=Lf		
Eco-indicator 99	Rec	<	Inc	<	Lf

7.12 Results Qualitative discussions

In addition to the scenarios presented more quantitatively there are some aspects that have been more roughly calculated and where results will only be qualitatively presented. These are degree of efficiency for the incineration plants and the characterisation of emissions defined as metals.

7.12.1 Incineration plant, degree of efficiency

In the study the incineration plant modelled for combusting household waste is assumed to have a degree of efficiency which is 0.90 MJ recovered/ MJ HHV, including flue gas condensation. (This equals 1.01 MJ/ MJ LHV). The incineration plants for forest residues and for natural gas have 1.06 MJ/ MJ LHV and 1.04 MJ / MJ LHV degrees of efficiency, respectively, including flue gas condensation as described in section 5.9. Assumptions concerning the degrees of efficiency may be of relevance for the final results, e.g. avoided environmental impacts from avoided heat production per MJ heat produced will decrease with a decreasing degree of efficiency for the waste incineration plant. In the case of using 0.74 instead of 0.90 for the waste incineration facility there are changes in many impact categories and these together may lead to a difference in the evaluation of the waste management options. In this case there is no change in the rankings, but using the Ecotax 98/EDIP there is a net contribution to environmental impacts from the incineration option, which is a change.

Assumptions regarding efficiencies of incineration facilities, as well as other technology may be of importance for the outcome of an assessment. Other technology assumptions are made in all the data choices, and uncertainty in these must be kept in mind.

7.12.2 Characterisation of metals as a group

In some process data metals emitted are not specified but simply reported as *metals* or *heavy metals* to air, water or soil. The uncertainty is high concerning the specific constituents of these grouped emissions. In some cases some metals are reported separately as well, which could mean that the metals reported as an aggregate are less toxic, but that can not be concluded. How these emissions are characterised within the toxicological impact categories is of importance. As a first option, a worst scenario was tried where the values for the metals with the highest characterisation values were chosen to represent the grouped emissions. As this resulted in a great dominance of metals in the toxicological impact categories and also in some cases in the total weighted results other options were tried.

The metal emissions connected to car transports made up a large part of the emission impacts and the original data (Frischknecht 1996) was consulted and the post was divided between the actual metals emitted. This lead to a major decrease in the impacts related to the metals for this process. For other processes where emissions of metals are aggregated, mainly electricity production from coal and in different aggregated production data, no such division is made. Instead the mean and median metal characterisation figures were calculated and tried. The mean was quite much larger than the median. For the base scenario the median characterisation values are chosen, both for aggregated emissions of metals and heavy metals.

The differences between the highest value and the mean are generally around a factor 10. The mean value is in turn higher than the median. Here the differences vary more depending on to which media the metals are emitted and in what media the toxicity is considered. Variations are from five times to a thousand (the highest mainly occurring for human toxicology with the EDIP characterisation). Even higher is the difference in one case, for terrester eco-toxicology with USES characterisation. This is for emissions to fresh water where the mean is 1.0E2 and the median 5.1E-19. In some cases in the EDIP characterisation method, there is only one metal (mercury) with a value in a category. These are the categories where the metal is transported from water or soil to air, soil or water. In these cases the value is consequently the same for the maximum, the mean and the median.

Concluding, it should be noted that the emissions of unspecified metals could be characterised in different ways and that there are significant and sometimes very large differences between the options.

7.13 Results Additional time perspectives on global warming

The gases contributing to global warming have different life times in the atmosphere. Global warming potentials (GWP) used in the characterisation of global warming may therefore be calculated for different time frames. In this scenario the calculations in the base scenario using a 100 year time frame are compared with calculations using the time frames 20 and 500 years. This mainly affects the landfill option where substantial emissions of methane occur. The GWP for methane varies from 56 CO_2-equivalents over a 20 year perspective, to 21 in a 100 year perspective and 6.5 in a 500 year perspective. The GWP of nitrous oxide (N_2O) also varies with time. For processes where there are significant emissions of N_2O, the results may depend on the time perspective chosen. The GWPs for the different time frames can be found in Appendix 2.

7.13.1 Global warming

Considering the whole system, the choice of time perspective does not alter the ranking for global warming (see Table 7.49). In the recycling alternatives emissions of greenhouse gases are avoided, while for incineration and landfilling there are net emissions. Although landfill gains in the 500 years perspective, incineration is still the better option. For food waste incineration is better than composting, while digesting still is the best and landfill the worst alternative when 20 years or 500 years perspectives are chosen.

7.13.2 Total weighted results

The ranking for the whole system weighted together remains unchanged as the time perspectives concerning global warming are changed (see Table 7.50). For food waste using the Ecotax 98/EDIP method and the 500 years perspective landfill becomes better than incineration. Digesting the food waste is still preferable, while composting still comes out as the worst alternative.

Table 7.49 The 100 year perspective for characterising contributions to the impact category global warming used in the base scenario is compared to 20 and 500 year timeframes. The table shows weighted results in the unit SEK/year, but the results can also be read as characterisation results, since the characterisation results have only been multiplied with a factor. In this case the weighting factor used is 0.37 SEK/kg CO_c.

				Different time frames for global warming						
	Whole system	Food waste	Newspaper	Corrugated cardboard	Mixed cardboard	PE	PP	PS	PET	PVC
Global warming 100 years										
Rec dig h/e	-2.4E+08	-4.6E+07	-2.2E+08	-1.2E+07	9.4E+06	1.1E+07	1.1E+07	6.5E+06	-4.6E+06	2.4E+06
Rec dig f	-2.4E+08	-5.0E+07								
Rec comp	-1.8E+08	7.2E+06								
Incineration	2.1E+08	8.8E+06	1.0E+07	1.6E+06	3.3E+07	1.2E+08	1.6E+07	1.3E+07	4.9E+06	2.4E+06
Landfill	8.5E+08	1.5E+08	2.5E+08	1.6E+08	1.2E+08	1.3E+08	1.8E+07	1.5E+07	5.3E+06	2.7E+06
Global warming 20 years										
Rec dig h/e	-2.8E+08	-5.2E+07	-2.6E+08	-1.7E+07	1.2E+07	1.2E+07	1.3E+07	6.8E+06	-4.6E+06	3.0E+06
Rec dig f	-2.7E+08	-4.3E+07								
Rec comp	-2.2E+08	1.2E+07								
Incineration	2.2E+08	9.0E+06	1.2E+07	2.6E+06	3.4E+07	1.2E+08	1.6E+07	1.4E+07	4.9E+06	2.4E+06
Landfill	2.0E+09	4.3E+08	6.9E+08	4.5E+08	2.7E+08	1.5E+08	2.0E+07	1.6E+07	5.7E+06	3.0E+06
Global warming 500 years										
Rec dig h/e	-2.2E+08	-4.4E+07	-2.0E+08	-9.6E+06	8.7E+06	1.1E+07	1.1E+07	6.3E+06	-4.6E+06	2.2E+06
Rec dig f	-2.2E+08	-5.0E+07								
Rec comp	-1.7E+08	8.4E+06								
Incineration	2.1E+08	6.3E+06	1.1E+07	2.2E+06	3.3E+07	1.2E+08	1.6E+07	1.4E+07	4.9E+06	2.4E+06
Landfill	3.5E+08	2.8E+07	6.0E+07	3.5E+07	6.5E+07	1.3E+08	1.7E+07	1.4E+07	5.1E+06	2.6E+06

Table 7.50 The 100 year perspective for characterising contributions to the impact category global warming used in the base scenario is compared to 20 and 500 year timeframes. The results shown are for all impact categories weighted together. The Ecotax 98 method has been applied in the combinations EDIP max, USES min and USES max as described in section 6.3 and the results for these are shown in SEK/year. The results from using the Eco-indicator 99 method are shown in points.

	Different time frames for global warming									
	Whole system	Food waste	Newspaper	Corrugated cardboard	Mixed cardboard	PE	PP	PS	PET	PVC
Total Ecotax 98/EDIP 100 years										
Rec dig h/e	-3.4E+09	-2.4E+08	-1.6E+09	7.3E+07	-1.2E+08	-1.2E+09	-8.7E+07	-5.1E+07	-2.0E+08	-2.9E+07
Rec dig f	-3.4E+09	-1.7E+08								
Rec comp	-3.1E+09	1.6E+08								
Incineration	-9.4E+07	3.6E+07	-1.0E+08	-5.7E+07	3.7E+06	1.7E+07	1.9E+06	4.1E+06	2.2E+06	1.6E+06
Landfill	6.1E+08	1.1E+08	1.4E+08	7.8E+07	9.5E+07	1.5E+08	1.9E+07	1.6E+07	6.1E+06	3.3E+06
Total Ecotax 98/EDIP 20 years										
Rec dig h/e	-3.4E+09	-2.4E+08	-1.7E+09	6.8E+07	-1.2E+08	-1.2E+09	-8.6E+07	-5.0E+07	-2.0E+08	-2.8E+07
Rec dig f	-3.4E+09	-1.7E+08								
Rec comp	-3.1E+09	1.6E+08								
Incineration	-8.9E+07	3.6E+07	-9.8E+07	-5.6E+07	4.3E+06	1.8E+07	2.0E+06	4.2E+06	2.2E+06	1.6E+06
Landfill	1.8E+09	4.0E+08	5.9E+08	3.7E+08	2.4E+08	1.6E+08	2.2E+07	1.7E+07	6.5E+06	3.6E+06
Total Ecotax 98/EDIP 500 years										
Rec dig h/e	-3.4E+09	-2.4E+08	-1.6E+09	7.5E+07	-1.2E+08	-1.2E+09	-8.8E+07	-5.1E+07	-2.0E+08	-2.9E+07
Rec dig f	-3.4E+09	-1.7E+08								
Rec comp	-3.0E+09	1.6E+08								
Incineration	-9.3E+07	3.4E+07	-9.9E+07	-5.6E+07	3.8E+06	1.8E+07	2.0E+06	4.2E+06	2.2E+06	1.6E+06
Landfill	1.1E+08	-8.4E+06	-4.7E+07	-4.5E+07	3.6E+07	1.4E+08	1.9E+07	1.5E+07	5.9E+06	3.2E+06
Total Ecotax 98/USESmin 100 years										
Rec dig h/e	-5.3E+08	6.8E+07	-4.9E+08	-3.5E+07	-1.7E+07	-5.0E+07	1.2E+07	8.2E+06	-2.5E+07	9.2E+05
Rec dig f	-4.4E+08	1.6E+08								
Rec comp	-4.2E+08	1.8E+08								
Incineration	6.7E+06	3.4E+07	-7.4E+07	-4.4E+07	9.8E+06	6.1E+07	7.9E+06	7.9E+06	3.0E+06	1.7E+06
Landfill	8.5E+08	2.0E+08	2.1E+08	1.4E+08	1.2E+08	1.3E+08	1.8E+07	1.5E+07	5.3E+06	2.8E+06
Total Ecotax 98/USESmin 20 years										
Rec dig h/e	-5.8E+08	6.3E+07	-5.3E+08	-4.1E+07	-1.5E+07	-5.0E+07	1.4E+07	8.6E+06	-2.5E+07	1.5E+06
Rec dig f	-4.8E+08	1.6E+08								
Rec comp	-4.6E+08	1.8E+08								
Incineration	1.2E+07	3.4E+07	-7.2E+07	-4.3E+07	1.0E+07	6.2E+07	8.0E+06	8.0E+06	3.0E+06	1.7E+06
Landfill	2.0E+09	4.8E+08	6.6E+08	4.3E+08	2.6E+08	1.5E+08	2.0E+07	1.6E+07	5.7E+06	3.0E+06

Table 7.50 Continued

	Different time frames for global warming									
	Whole system	Food waste	Newspaper	Corrugated cardboard	Mixed cardboard	PE	PP	PS	PET	PVC
Total Ecotax 98/USESmin 500 years										
Rec dig h/e	-5.1E+08	7.1E+07	-4.8E+08	-3.3E+07	-1.8E+07	-5.0E+07	1.1E+07	8.1E+06	-2.5E+07	7.1E+05
Rec dig f	-4.3E+08	1.6E+08								
Rec comp	-4.0E+08	1.8E+08								
Incineration	7.7E+06	3.2E+07	-7.3E+07	-4.3E+07	9.9E+06	6.2E+07	8.0E+06	8.0E+06	3.0E+06	1.7E+06
Landfill	3.5E+08	8.1E+07	2.5E+07	1.3E+07	6.3E+07	1.3E+08	1.7E+07	1.4E+07	5.2E+06	2.6E+06
Total Ecotax 98/USESmax 100 years										
Rec dig h/e	-8.3E+09	1.5E+09	-2.6E+09	5.8E+06	-2.3E+09	-2.8E+09	-4.6E+08	-3.5E+08	-1.0E+09	-3.1E+08
Rec dig f	-8.1E+09	1.8E+09								
Rec comp	-7.6E+09	2.3E+09								
Incineration	1.5E+10	2.2E+09	5.3E+09	1.7E+09	1.7E+09	3.1E+09	4.2E+08	3.4E+08	1.8E+08	1.4E+08
Landfill	1.7E+10	2.3E+09	6.0E+09	2.0E+09	1.9E+09	3.7E+09	4.9E+08	3.9E+08	2.0E+08	1.5E+08
Total Ecotax 98/USESmax 20 years										
Rec dig h/e	-8.4E+09	1.5E+09	-2.7E+09	5.8E+05	-2.3E+09	-2.8E+09	-4.5E+08	-3.5E+08	-1.0E+09	-3.1E+08
Rec dig f	-8.2E+09	1.8E+09								
Rec comp	-7.6E+09	2.3E+09								
Incineration	1.5E+10	2.2E+09	5.3E+09	1.7E+09	1.7E+09	3.1E+09	4.2E+08	3.4E+08	1.8E+08	1.4E+08
Landfill	1.8E+10	2.6E+09	6.4E+09	2.3E+09	2.0E+09	3.7E+09	5.0E+08	4.0E+08	2.0E+08	1.5E+08
Total Ecotax 98/USESmax 500 years										
Rec dig h/e	-8.3E+09	1.5E+09	-2.6E+09	7.8E+06	-2.3E+09	-2.8E+09	-4.6E+08	-3.5E+08	-1.0E+09	-3.1E+08
Rec dig f	-8.1E+09	1.8E+09								
Rec comp	-7.6E+09	2.3E+09								
Incineration	1.5E+10	2.2E+09	5.3E+09	1.7E+09	1.7E+09	3.1E+09	4.2E+08	3.4E+08	1.8E+08	1.4E+08
Landfill	1.7E+10	2.2E+09	5.8E+09	1.9E+09	1.8E+09	3.7E+09	4.9E+08	3.9E+08	2.0E+08	1.5E+08

8. Discussion and overall conclusions

8.1 Summary of some of the results

8.1.1 Introduction

All waste treatment methods considered in this study produce some useful products: material, fuel, fertilisers, heat or electricity, which can replace the same product produced in another way. It is important to note that the environmental aspects of different waste treatment methods are therefore not only determined by the properties of the treatment method itself, but also by the environmental properties of the product that can be replaced and the environmental impacts associated with its life cycle.

It is also interesting to note that the results presented in chapter 7 often are negative, which means that environmental interventions can be avoided. This is an illustration of the saying that waste can be regarded as a resource. The reason for this is that the waste comes into the studied systems without any environmental burdens associated to it. If the upstream processes had been included as well, there would probably not have been any negative results at all. The results presented here should therefore not be taken as an argument for a “waste maximisation” policy.

In this section some of the results presented in chapter 7 will be summarised and highlighted. The focus here is on energy use, emissions of greenhouse gases and the total weighted results. In the beginning the focus is on the whole system and the paper and plastic fractions separately. As noted in section 2.3.3 the calculations have been made for the unrealistic situation that all waste included is treated with the same strategy. In the presentation of results in this chapter, recycling of the paper and plastic waste fractions is combined with digestion of the food waste where the produced biogas is used for production of heat and electricity.

8.1.2 Energy use

Results for the total energy use is shown in Figure 8.1 for newspaper, PET, food waste and the whole system for the base scenario. The total energy use is for all treatment methods negative for the whole system. This implies that the energy output from the system is larger than the energy input (excluding the energy content of the waste, which is constant in all cases and therefore disregarded). The order of preference between the treatment options is recycling of materials is better than incineration which is better than landfilling for the whole system when looking at total energy requirements (food waste is different and discussed below). This result is robust. In fact this result is constant for the whole system in all studied scenarios, Figure 8.2. The ranking is also constant for newspaper and PET in all scenarios in this study and constant for all paper and plastic materials in the base scenario.

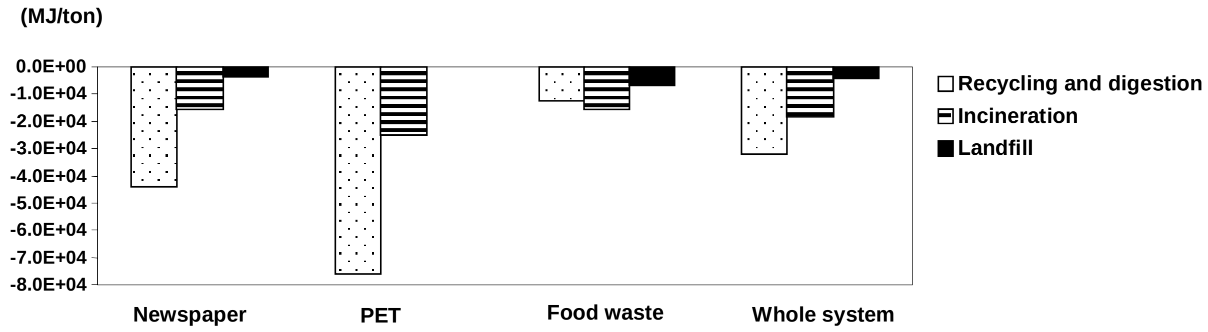

Figure 8.1 Results for the total energy use for newspaper, PET, food waste and the whole system in the base scenario. The results are presented per ton waste.

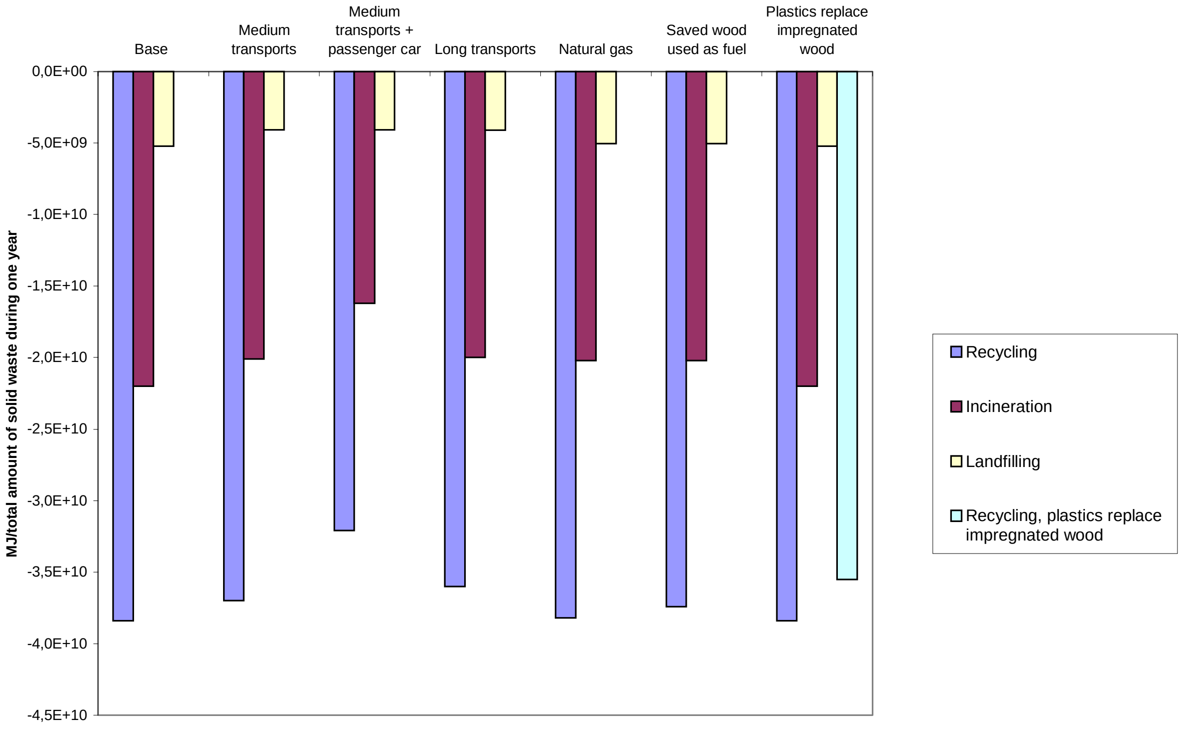

Figure 8.2. The total energy use for the whole system in different scenarios. The results are presented per total amount of solid waste produced during a year (amounts are presented in chapter 4).

Results for non-renewable energy use for the base scenario are shown in Figure 8.3. These results show a slightly different order: recycling is preferable to landfilling which is preferable to incineration. The results for non-renewable fuels are however sensitive to the assumptions made concerning the avoided heat production and the use of wood saved in recycling of paper fractions as can be noted in Figure 8.4 which shows the results for the whole system in different scenarios.

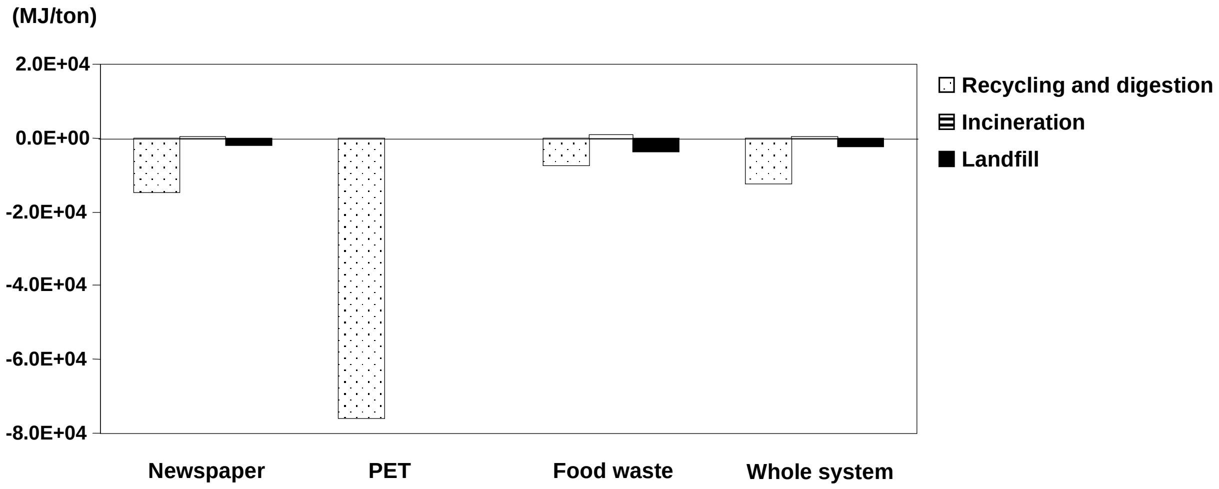

Figure 8.3 Results for use of non-renewable energy for newspaper, PET, food waste and the whole system in the base scenario. The results are presented per ton waste.

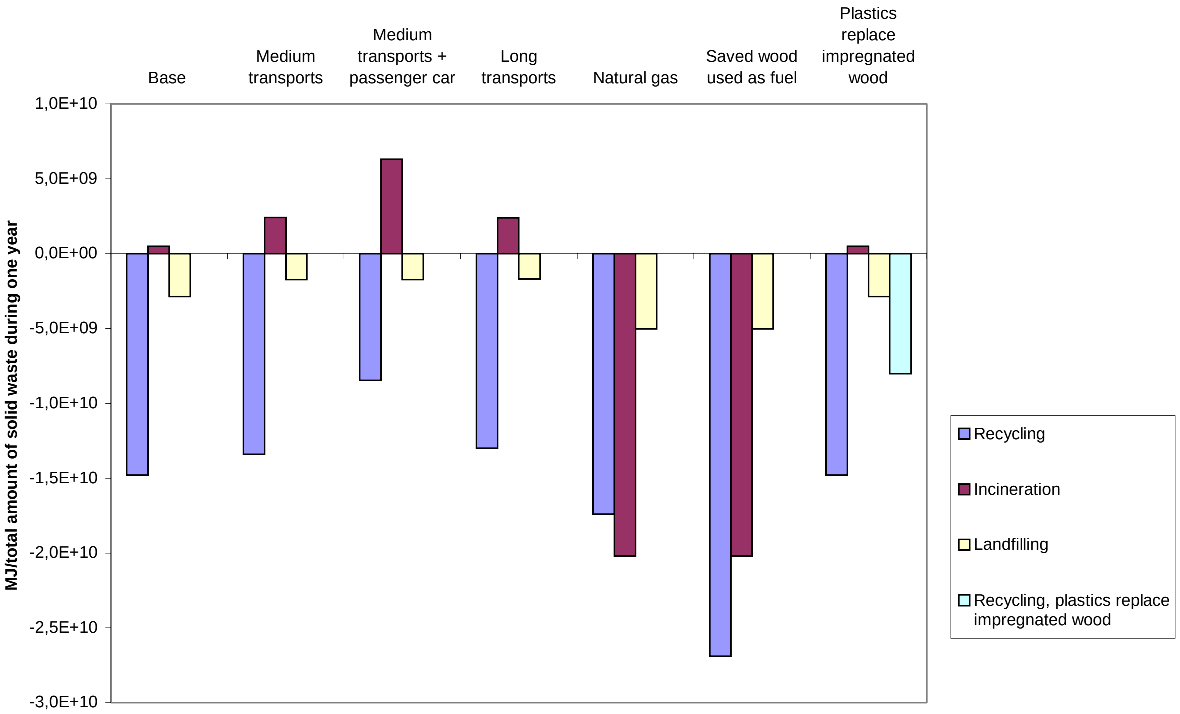

Figure 8.4. The use of non-renewable energy for the whole system in different scenarios. The results are presented per total amount of solid waste produced during a year (amounts are presented in chapter 4).

8.1.3 Global warming

Results for global warming are shown in Figure 8.5 for the base scenario. Also in this case the order of preference is recycling is better than incineration which is better than landfilling for the paper and plastic materials. This result is fairly robust. It is valid for all plastic and paper materials in the base scenario (section 7.2.5). The order of preference between incineration and landfilling is however for some materials sensitive to the modelling of landfills (when only a shorter time period is considered the results for landfilling is improved) and also for assumptions concerning transportation of waste in passenger cars for some waste fractions. However, in all these cases, recycling is still the most preferable option. The results for the whole system in different scenarios are presented in Figure 8.6.

Figure 8.5 Results for global warming for newspaper, PET, food waste and the whole system in the base scenario. The results are presented per ton waste.

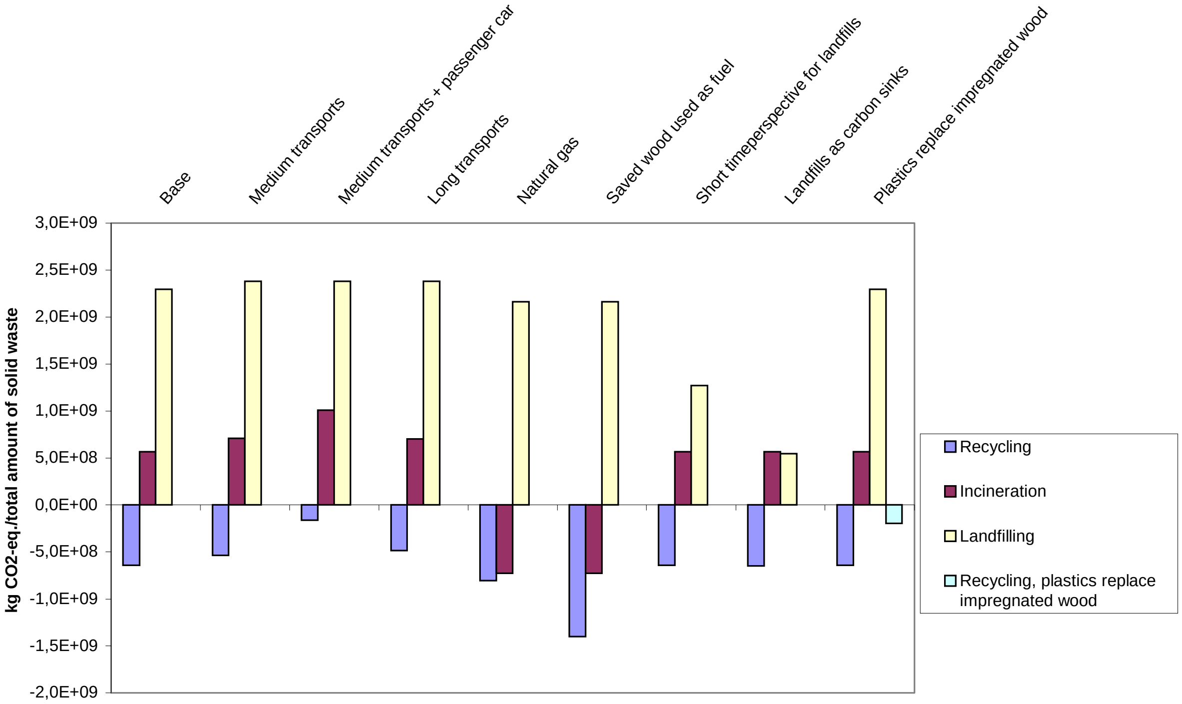

Figure 8.6. Contribution to global warming for the whole system in different scenarios. The results are presented per total amount of solid waste produced during a year (amounts are presented in chapter 4).

8.1.4 Total weighted result

When looking at the total weighted results, the order of preference is again, recycling is preferable to incineration which is preferable over landfilling, for the whole system in the base scenario. Again, this result is fairly robust. It is valid for the whole system, newspaper and PET in most scenarios. Figure 8.7 shows the weighted results using the Ecotax98/USESmax method. It can be noted that transportation by passenger cars can have a significant influence on the total results according to this weighting method. However, according to the other weighting methods used, the influence is less significant and does not change the ranking between recycling and other treatment methods. The ranking between incineration and landfilling can be changed by the modelling of landfills as well as assumptions regarding transport distances.

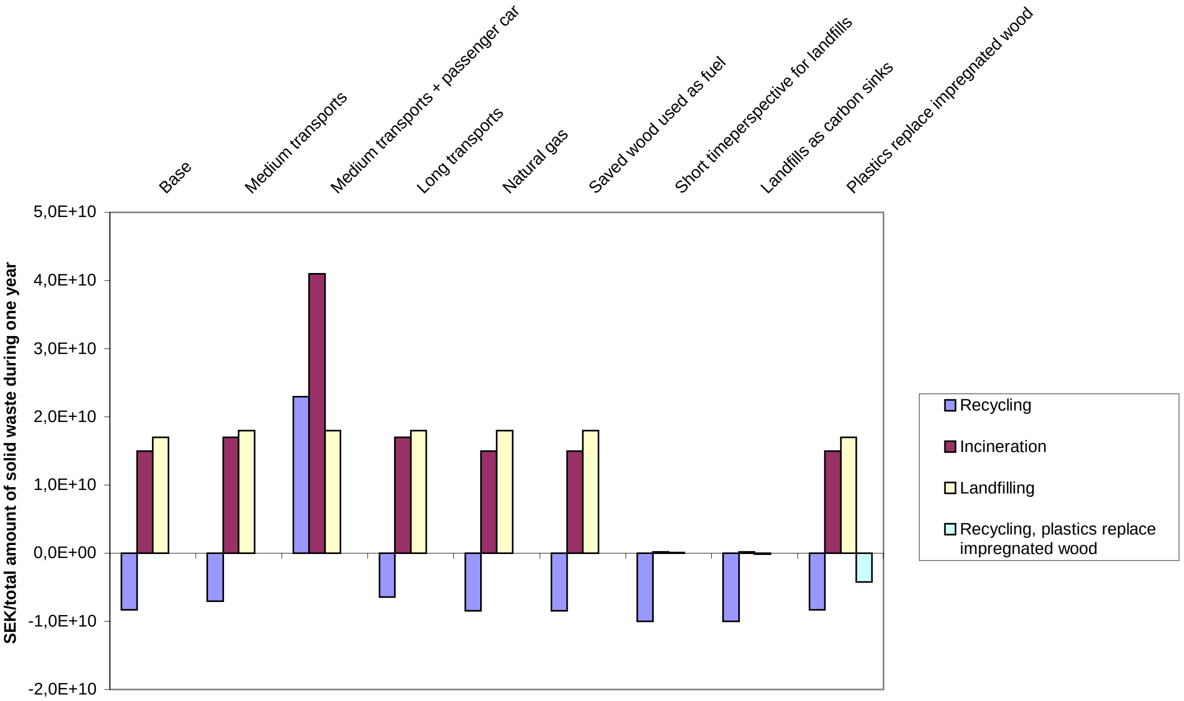

Figure 8.7. Total weighted results for the whole system using the Ecotax98/USESmax weighting method. The results are presented per total amount of solid waste produced during a year (amounts are presented in chapter 4).

8.1.5 Food waste

For food waste, composting, digestion, incineration and landfilling are compared. The ranking between these alternatives vary between different impact categories and between different scenarios. For total energy use, incineration is more efficient than digestion. Composting is the only alternative which needs an energy input. The results for global warming are sensitive for assumptions regarding the alternative fuel and whether both heat and electricity or fuel for vehicles are produced in the case of digestion. The results are also sensitive to assumptions regarding transport distances.

In general anaerobic digestion is preferable over composting and landfilling regarding energy use, emissions of greenhouse gases and total weighted results. The ranking between digestion and incineration varies for different impact categories and in different scenarios. Also the ranking between composting and landfilling varies for different impact categories and in different scenarios. Composting could be an interesting alternative if transport distances are kept low while they are long for the other treatment alternatives. Large-scale composting is therefore probably of limited interest, while home composting or small scale composting requiring only limited transportation could be an alternative, but as a general result the advantages of composting are limited.

When discussing treatment of food waste it should however be noted that several key assumptions have been made. For example, it has been assumed that the residues from composting and digestion can be used as fertilisers which is not certain due to the risk of pollutants in the residues. It is also assumed that the residues can replace artificial nitrogen and phosphorous fertilisers but no credit is given to the organic material or micro-nutrients. Another important assumption is that similar emissions of nitrogen and phosphorous will occur from digestion and composting residues as from artificial fertilisers. However, this is a simplification, which underestimates the emissions from the residues (Dalemo 1999).

8.2 Results compared to national references

In Table 8.1, some of the results for the base scenario of the whole system are summarised. As noted above the calculations in this study have been made for the unrealistic situation that all waste included is treated with the same waste strategy. The results can therefore be regarded as potentials which can never be realised. For the total energy use it can be noted that the energy savings when going from landfilling to incineration is approximately 5 TWh. An additional 4-5 TWh can be saved in the case of recycling instead of incineration. These numbers can for example be compared with the total energy used for district heating in Sweden which is 44 TWh (section 3.3) and the total energy input in Sweden which is 480 TWh (Energimyndigheten 1999).

Table 8.1. Some results for the whole system in the base scenario.

	Total energy [TWh]	**CO_2-eq [million ton]**	**Total result EDIPmax [SEK]**	**Total result USESmin [SEK]**	**Total result USESmax [SEK]**
Rec dig	-11	-0,6	-3,4E+9	-0,53E+9	-8E+9
Incineration	-6	0,6	-0,1E+9	0,01E+9	15E+9
Landfill	-1	2,3	0,8E+9	0,87E+9	17E+9

Also in Table 8.1, the emissions of greenhouse gases are expressed as CO_2-equivalents. The potential savings that can be made when going from incineration to recycling is 1.2 million ton CO_2-equivalents. This number can be compared to the total emissions of greenhouse gases in Sweden 1998 which were 75 million ton (SOU 2000) or the goal to reduce the greenhouse gas emissions with 2% until the year 2010 compared to the emissions 1990.

The results in Table 8.1 are for the base scenario. In the scenarios with shorter time-perspectives for landfills the emissions of greenhouse gases are significantly reduced, by up to 75 %, making the results for the incineration and landfilling alternatives quite similar. Also the total weighted results are significantly changed when only a shorter time-period is considered. This is because emissions from landfills of for example greenhouse gases and toxic compounds will continue after the short time-period (which is approximately one century) has ended.

When using the weighting method Ecotax 98, the results are expressed in monetary units, as [SEK]. As explained in chapter 6, the monetarisation is based on Swedish taxes and fees. If it is assumed that these taxes and fees represent the value of the damages on the environment, the results can be seen as a minimum representation of the damages that different treatment options may cause. They are minimum values since there are a number of environmental aspects that are not included adequately in this study, this is further discussed below. In Table 8.1 it can be noted that the results differ between the different versions of the weighting method. The differences between the Total Ecotax 98/EDIP and the Total Ecotax 98/USESmax methods are different methods for characterising the toxicological impacts requiring partly different valuations. This difference can therefore partly be seen as an indication of the uncertainty in the natural science based part of the impact assessment method. The difference between the Total Ecotax 98/USESmin and Total Ecotax 98/USESmax results can be seen as an indication of the uncertainty in the societal valuations since different bases for deriving the weighting factors have been used.

If the assumption is made that the taxes and fees used as a basis for the weighting method can be used as an estimation of the value of the damages, it can be noted that landfilling cause environmental problems which are valued between 800 million SEK and 17.000 million SEK. At the other end, recycling will decrease environmental damages valued between 500 and 25.000 million SEK according to this weighting method compared to incineration or landfilling.

8.3 Impact assessment methods

The most important impact categories in this study, according to the Ecotax 98 weighting method are in general abiotic resources, global warming, toxicological impacts and photo-oxidant formation. The toxicological impacts are both human toxicological and ecotoxicological impacts. It is not surprising that toxicological impacts are of importance when discussing waste management systems. It is however of interest to note this, since toxicological impacts are often excluded from LCAs and similar studies of waste management systems. The emissions of toxicological importance according to the used methods come from various sources, e.g. metals in the waste materials emitted from the different treatment methods, mercury and other metals from coal incineration, metals in the ashes from incineration of forest residues, VOCs from production of plastics, VOCs and metals from trucks and cars, etc. Emissions of toxic compounds from transportation, especially with passenger cars can have a significant contribution to the total results.

It is interesting to note that the results are similar for both weighting methods that are used: Ecotax 98 and Eco-indicator 99, with regard to the ranking of different treatment alternatives. This is interesting to note since the weighting methods are quite different, based on different principles and methods. However, it can be noted that they do give different results concerning the identification of the most important interventions. For example, Ecoindicator-99 gives much more weight to human health impacts caused by emissions of toxic compounds to air and much less weight to impacts caused by global warming. For both methods, resources are of importance.

8.4 Limitations and need for further research

It is important to note that not all relevant environmental impacts are included in this study. A reference can be made to the default list of impact categories in Table 2.1 and the list of impact categories included in this study in Table 2.2. For example, impacts from land use are not at all included in this study (except for some processes, which are considered in the Eco-indicator 99 method). This is of relevance for example when discussing forestry. Also, impacts in work environment, casualties, noise and odour are not at all included. The toxicological impact categories are plagued with datagaps. This is of relevance for example when discussing additives in plastics and paper and the whole range of different possible micropollutants that may occur in mixed wastes. Impacts associated with nuclear power are omitted in this study (although the use of nuclear power within the studied systems is limited since the aim has been to use coal fired power plants as the source for marginal electricity). These datagaps indicate that conclusions on an overall level should be drawn cautiously.

The data gaps discussed above adds to the overall uncertainty, which can be fairly large as discussed in chapter 2. This is one reason why the focus here is on total energy use and emissions of greenhouse gases. The uncertainties associated with these impact categories are somewhat lower than for other categories. It should however be noted that many of the results presented here are fairly robust in the sense that they do not change much with changing assumptions in different scenarios. It is also interesting to note that many of these results are similar to the results obtained in previous studies for example on paper and plastic materials e.g. Baumann et al. (1993), Denison (1996), Ekvall et al. (1998), Finnveden and Ekvall (1998), Heyde and Kremer (1999), Ekvall and Finnveden (2000a) and Sundqvist et al. (2000). Both these aspects increase the confidence in the conclusions drawn here.

This study has focused on fractions of municipal solid waste. However, it is expected that the methodology, much of the data and possibly also much of the results are applicable to other waste streams such as different types of industrial wastes and construction and demolition wastes.

Although several scenarios have been studied, there are still some aspects that would be interesting to study further. One example is the role of the competing heat source. Here two energy sources were used, forest residues and natural gas. Other energy sources could be of interest such as oil. The modelling of forest residues have some limitations, for example concerning the emissions of toxic compounds, the description of elements which are part of biogeochemical cycles and impacts associated with land use. It would also be interesting to try different sources of electricity, for example from renewable sources and see how that could influence the results. The data quality varies across the different processes. Especially some of the recycling process would benefit from better data. In general, emissions with toxicological impacts and impacts from land use need further attention. The use of passenger cars has turned out to be a factor which may significantly influence the results. Better data on actual behaviour would be of interest in order to reduce the dependence on assumptions. Since the interesting questions relate to future situations, data relevant for change-oriented strategic studies are wanted, but to a large extent lacking.

8.5 Summarised conclusions

To summarise some of the overall conclusions it can be noted that recycling of paper and plastic materials are in general favourable according to our study with regard to overall energy use, emissions of gases contributing to global warming and the total weighted results. One important exception is when recycled plastics replace impregnated wood. In this case recycling of plastics is less favourable than incineration with respect to energy use and emissions of greenhouse gases although the difference is rather small. However, recycling may still be favourable with respect to toxicological impacts, and our results still show benefits for recycling with regard to total weighted results.

Incineration is in general favourable over landfilling according to our study with regard to overall energy use, emissions of gases contributing to global warming and the total weighted results. There are however some aspects which may influence this ranking. If longer transportation distances are demanded in the incineration case, especially by passenger cars, landfilling can become more favourable than incineration. The modelling of landfills can also have a decisive influence. If shorter time periods are used (in the order of a century) landfilling is favoured and may become a preferable option over incineration.

LCAs can be used to test the waste hierarchy and identify situations where the hierarchy is not valid. Our results suggest however that the waste hierarchy is valid as a rule of thumb.

8.6 Policy implications

The policy implications of the results presented here depend on the aim of the policy. The discussion here takes as a starting point that one aim of the policy is to reduce the total use of energy and emissions of gases contributing to global warming.

The results presented here suggests that a policy promoting recycling of paper and plastic materials should be pursued, preferably combined with policies promoting the use of recycled plastics replacing plastics made from virgin materials. The study presented here also suggests that if biomass saved from increased recycling can be used as fuels replacing fossil fuels, this can reduce emissions of greenhouse gases. Although increased transportation in general does not affect the ranking between recycling and other treatment methods, transportation of waste materials should be minimised. It is especially of importance to design the source separation systems so that transportation by passenger cars can be avoided since such transports can reduce the benefits from recycling.

In the system studied here, heat from incineration of waste has replaced either heat from forest residues or natural gas. If the waste can replace oil or coal as energy sources, and neither biofuels nor natural gas is an alternative, a policy promoting incineration may be successful for paper materials regarding emissions of greenhouse gases (Finnveden and Ekvall 1998, Ekvall and Finnveden 2000c).

In situations where recycling is not an alternative, a policy promoting incineration is generally better than a policy promoting landfilling. However, in a short time-perspective, incineration may lead to increased emissions of greenhouse gases compared to landfilling of materials which are not easily degradable such as plastics and some constituents of paper materials. If source separation of fractions to be incinerated is practised, it is important that the systems are designed so that transportation (especially with passenger cars) can be minimised.

For food waste, the study presented here does not provide clear answers to the comparison between incineration and anaerobic digestion. Neither landfilling nor composting however, does in general seem to be attractive strategies if the aim is to reduce the use of energy and emissions of greenhouse gases. An exception may be if large transport distances can be avoided. In such situations, home, or small scale composting may be attractive although this has not been studied here.

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Appendix 1

Sources for data on additives, energy and transports

In this appendix sources for data on additives, transports, fuels, heat and electricity that have been used in the study, which are either taken from existing Sima Pro databases or documented by FOA/fms, are shortly presented. The first name in each headline is the name as stated in the inventories. The descriptions include information on who recorded the data and with which references. Inputs from the technosphere are presented, this means inputs that in turn have data inventoried for their production. The materials, energy and transport written in *italics* are further described elsewhere in the appendix. The full references, as documented in Sima Pro, are presented at the end of this appendix. Complete process data records for all processes are available in Appendix 5.

Additives

Active pesticide

Record: IVAM
References: Weidema (1995)

Inputs from technosphere: *Ethene IVAM*
Energy: *MJth ind energy (set: ETH/CBS)*

Generic data. No specific data on emissions or raw materials. Data are presented for energy use and estimations are made on maximum total water emissions of pesticides and degradation and intermediate products.

Additive, newspaper recycling

Record: fms/FOA
References: REFORSK 1993

Energy: *Electr. hard coal* and *Heat from heating oil*

Production and transport of additive used in recycling of newspaper into pulp.

Aluminium sulphate - ($Al_2(SO_4)_3$)

Record: PRé Consultants
References: BUWAL 250 (1996). Data according to Nann (1995)

Input from technosphere: *Sulphuric acid B250*
Energy: *Electricity UCPTE B250*
Transport: *Train (diesel & electric) B250*

The resources used in production are process water, aluminium hydroxide (not traced back) and sulphuric acid. No data for process emissions to air or waste production are presented.

Ammonia - (NH_3)

Record: IVAM
References: Ullmann (1985), EPA (1985), Energikentallen 2 (1992) and SPIN N-Fertiliser (1995).

Inputs from technosphere: S*ynthesis gas* and N_2
Energy: *MJth gas energy*

Inputs to the production of ammonia are water, synthesis gas and N_2 (N_2 from air destillation is described under oxygen). Energy use does not include extraction and transportation.

Ammonia P - (NH_3)

Record: PRé Consultants
References: PWMI report 14 PMMA (APME)

Data are aggregated.

Calciumhydroxide - ($CaOH_2$)

Record: IVAM
References: IVAM (1993), Energikentallen 1 (1992), Rijksuniversitet Utrecht (1991) and EPA (1985).

Energy: *MJth ind energy (set: ETH/CBS)* and *MJel NL model (set:ETH + grid).*

No specific production data for $CaOH_2$ was available, according to IVAM. Data presented include no specific production data, the energy requirement is assumed to be the same as for NaOH production and emissions data are from production of slaked (hydrated) lime.

Chlorine NL – (Cl_2)

Record: IVAM
References: Bergh and Jurgens (1990), H.M.Ceasar et al. PVC en Ketenbeheer,
Stuurgroep PVC & Milieu, 1992., BUWAL 132 (1990), [Tiemersma: Anorganische basischemicaliën, een verkenning, Scriptie Scheikunde, VU Amsterdam.

Inputs from technosphere: *Rock salt IVAM*
Energy: *MJth ind energy (set: ETH/CBS)*

The production of chlorine is made through electrolysis of vacuum salt and is also giving *Interm. NaOH*. Allocation is made by mass. The inputs in the inventory data are water and rock salt. No data for producing vacuum salt out of rock salt are presented.

Dolomite

Record: IVAM
References: BUWAL 132 (1990)

Energy: *MJth gas energy, MJth light fuel oil* and *MJel UCPTE model*

Waste is not followed to the grave, reported as solid emissions.

Ethene IVAM

Record: IVAM
References: Bergh and Jurgens (1990), Energikentallen 1 (1992), Handbook of emissions factors

Inputs from technosphere: *Naphta IVAM*
Energy: *MJth heavy fuel oil*

Ethene is produced together with propene, interm. Benzene, interm. Ethylbenzene, interm. Butadiene, butane and petrol in the process of thermal cracking. Allocation is based on mass. Oil sludge and NaOH are reported as solid emissions. Emission factors are from Dutch producers and M.E. Reinders.

H_2 – (Hydrogen)

Record: IVAM
References: Kunststoffe (1980)

Inputs from the technosphere: *Synthesis gas*

H_2O_2 – (Hydrogen peroxide)

Record: IVAM
References: BUWAL 132 (1990)

Energy: *MJth ind energy (set: ETH/CBS)* and *MJel NL model (set: ETH+grid)*

No specific data available.

H_2SO_4 – (Sulphuric acid)

Record: IVAM
References: BUWAL 132 (1990)

Energy: *MJel NL model (set: ETH+grid)*

Inputs to the process are water and sulphur.

HCl (100%) B250 – (Hydrochloric acid)

Record: PRé Consultants
References: BUWAL 250 (1996) and Ullmann (1993)

Inputs from technosphere: *NaCl (100%)* and S*ulphuric acid*
Energy: *Heat oil (S, EU) B250* and *Electricity UCPTE B250*

Sodium sulphate is produced together with hydrochloric acid.

HCl – (Hydrochloric acid)

Record: IVAM
References: Emissieregistratie

Inputs from the technosphere: *Chlorine NL* and H_2

HNO_3 – (Nitric acid)

Record: IVAM
References: Energikentallen 2 (1992), Ullmann, SPIN N-fertiliser (1995)

Inputs from technosphere: O_2 and A*mmonia*
Energy: *MJel gas Holland* and avoided *Steam (BUWAL 1991)*

Data are for the oxidation of ammonia into HNO_3. Inputs are platinum in ore, O_2 and ammonia. Electricity used is from natural gas. Steam generated during the process is included as avoided production of steam.

Interm. NaOH

For a description of the production process see Chlorine NL.

K_2O

Record: IVAM
References: G.A. Reinhardt: Energie- und CO2-Bilanzierung nachwachsender Rohstoffe,
Vieweg, 1993.

Energy: *MJth ind energy (set: ETH/CBS)*

Inventory data only for energy use, no raw materials or emissions from production provided.

KAS – ($Ca(NO_3)_2$)

Record: IVAM
References: Energikentallen 1 (1992), G.A. Reinhardt: Energie- und CO2-Bilanzierung nachwachsender Rohstoffe Vieweg, 1993., SPIN N-Fertiliser (1995) and Tillmann (1992).

Inputs from technosphere: *Dolomite* and NH_4NO_3
Energy: *MJel NL model (set: ETH+grid)*

KAS is $Ca(NO_3)_2$. In production NH_3 is a by-product. Allocation has been done on mass basis.

Lime bj – (CaO)

Record: PRé Consultants
References: Bergh and Jurgens (1990)

Inputs from technosphere: *Lime stone bj*

Production waste is inventoried as solid emissions.

Lime stone bj – ($CaCO_3$)

Record: PRé Consultants
References: Bergh and Jurgens (1990)

Inputs from nature are limestone and crude oil. Waste from fuel mining are not followed to the grave but inventoried as solid emissions.

Limestone B250 – ($CaCO_3$)

Record: PRé Consultants
References: BUWAL 250 (1996)

Energy: *Heat diesel B250*

Resources used are limestone, lubricant (not traced back) and lubricating oil (not traced back). The energy use can vary substantially between sites. Data are derived from one company in Germany. No water emissions are specified.

Limestone IVAM

Record: IVAM
References: Energiekenatllen 2 (1992) and BUWAL 132 (1990)

Energy: *MJth diesel (BUWAL), MJth gas energy* and *MJel UCPTE model*

Material known, no data

Record: IVAM
References: No reference

The composition of the material is known but no process (data) are available (yet). This process is made to show in the inventory of substances how much of material is not accounted for.

N_2 - Nitrogen

See oxygen.

Na_2SO_4 – (Sodium sulphate)

Record: IVAM
References: BUWAL (132)

Inputs from technosphere: H_2SO_4
Energy: *MJth light fuel oil* and *MJel UCPTE model*

Na_2SO_4 assumed to be derived from H_2SO_4, a waste product from industrial processes (metal production) or desulphuring units (gas production). Input from nature recorded is water.

NaCl (100%) – (Sodium chloride)

Record: PRé Consultants
References: BUWAL 250 (1996)

Data for the production of NaCl (100%) are refered to BUWAL 250 (1996). In BUWAL some modifications and additions have been made to data originally provided by APME. Data for energy use are aggregated with other production data. Waste is not followed to the cradle but reported as solid emissions.

$NaClO_3$ – (Sodiumchlorate)

Record: IVAM
References: Ullmann

Inputs from technosphere: *Rock salt IVAM* and *HCl*
Energy: *MJth gas energy, MJth heavy fuel oil* and *MJth coal energy*

No specific emissions data are, according to IVAM, available. Inputs to the process are water, rock salt and HCl. The energy used is from natural gas, heavy fuel oil and coal. Solid waste is not followed to the cradle.

NaOH 50% - (Sodium hydroxide)

Record: IVAM
References: Bergh and Jurgens (1990) and BUWAL 132 (1990).

Input from technosphere: *Interm. NaOH*
Energy: *Steam (BUWAL 1991)*

NaOH P 1998 – (Sodium hydroxide)

Record: PRé Consultants
References: PWMI Report 6 PVC revised

Included are energy as feedstock and fuel, and other resources. Data are aggregated. Waste produced are not followed to the grave but inventoried under solid emissions.

NH_4NO_3 – (Ammonium nitrate)

Record: IVAM
References: SPIN N-fertiliser (1995)

Inputs from technosphere: A*mmonia* and HNO_3
No emissions data presented.

Naphta IVAM

Record: IVAM
References: Bergh and Jurgens (1990), W. Bruijn et al.: Karakterisering van raffinaderijen, Badger BV Den Haag 1984, Kunststoffe (1980) and Energiekentallen 1 (1992)

Input from technosphere: O*il for refinery*
Naphta is produced together with kerosene, light gasoil, heavy gasoil and atmospheric residue.

O_2 - Oxygen

Record: IVAM
References: Air Products Holland b.v., mr. Bolle (1992) and Ullmann

Energy: *MJel NL model (set: ETH + grid)*

O_2, N_2 and argon are produced out of air destillation. No emissions data are provided. Purification of argon is not included. Allocation is made on mass basis.

P_2O_5

Record: IVAM
References: SPIN P-fertilizer (1992)

Inputs from technosphere: H_2SO_4
Energy: *MJel NL model (set: ETH+grid)* and *Steam (BUWAL 1991)*

Inputs to the process are phosphate ore and H_2SO_4.

Phosphoric acid I - (H_3PO_4)

Record: Delft University of Technology
References: Emissieregistratie

Data for the production of phosphoric acid (H_3PO_4) are average data from 1990 for production in the Netherlands. Feedstock and energy use is not included, the only data supplied are emissions to water.

Potato S max

Record: IVAM
Reference: Chalmers (1991)

Inputs from technosphere: *KAS, Triple super phosphate, K2O* and *Active pesticide*
Transport: *Tractor 68 kW*

Production starts from seed-potatoes. No emissions from fertilisers are assumed.

Quicklime - (CaO)

Record: IVAM
References: Energiekentallen 2 (1992), BUWAL 132 (1990),Franklin: The comparative energy and environmental impacts for soft drink delivery systems 1987 to 1999,
Franklin Associates Ltd, March 1989, personal comment H.M.L. Schuur, Research Centrum Kalkzandsteenindustrie (RCK), Hilversum, May 1996 / April 1998and Ullmann

Input from technosphere: *Limestone IVAM*
Energy: *MJth gas energy, MJel UCPTE model*
Transport: *Rivertransport*

Calcination of limestone into quicklime (CaO) by heating in rotary kilns or kettles.

Pulp for cardboard

Record: PRé Consultants
References: BUWAL 132 (1990)

Input from technosphere: *Lime bj*
Energy: *Electricity without emission B*

Inputs from nature are recorded as wood, unspecified energy and sulphur. Produc. waste (not inert) is recorded as soled emissions.

Rock salt IVAM

Record: IVAM
References: BUWAL 132 (1990)

Energy: *MJth gas energy, MJth coal energy, MJth heavy fuel oil and MJel NL model (set; ETH + grid)*
Transport: *Truck 16f*

Resources used are rock salt and water.

Sodium sulphate B 250 – ($NaSO_x$ and Na_2SO_4)

Sodium sulphate is produced together with HCl from NaCl and sulphuric acid. For a description see HCl (100%) B250.

Starch NL (potato) max

Record: IVAM
References: SPIN Starch (1994), L. Leible: Technology Assessment on renewable raw materials: potentials and risks of the use of starches, Starch/Stärke 48, p. 121-130 1996 and VITO: Personal communication of public data used in an LCA on maize starch production (1996, based on data from 1994?).

Inputs from technosphere: *Potato S max* and *Wastew. treatment industry*

Energy: *MJth gas energy* and *MJel NL model (set: ETH+grid)*
Transport: *Truck 16f* and *Truck 16e*

Starch used is here assumed to be potato starch. Huizinge and Etman (1994) have gathered data from 1989 for SPIN, using Swedish data for potato production. The inputs for production of potato starch are water and potato. Waste produced is not followed to the grave, but it is inventoried under solid emissions. No allocation is made to the by-product, fodder.

Sulphur B250 – (S)

Record: PRé Consultants
References: BUWAL 250 (1996)

Energy: *Heat oil (S, EU) B250*

Sulphur is derived from recovery in a de-sulphurisation unit in an oil refinery.

Sulphur dioxide B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Sulphur dioxide (SO_2) can be produced by burning elementary Sulphur, H_2S (oil-refinery) or FeS_2 (de-sulphurisation of iron ores). The input from nature is here recorded simply as sulphur. Since the chemical reaction is exothermic, no energy input is required. The emission of SO_2 to the air is estimated 1%. Waste water production does not occur. No data on waste production.

Sulphuric acid B250 – (H2SO4)

Record: PRé Consultants
References: BUWAL 250 (1996), Data are derived from Lungi (1995).

Input from technosphere: *Sulphur B250*

The process is energetically self-sufficient. Data for waste is not available.

Synthesis gas

Record: IVAM
References: BUWAL 132 (1990), Montfrans et al, 1988 (=Delfstoffen en samenleving SDU, Den Haag, 1989?). Gasnummer No. 4 april 1992 and Energikentallen 1 (1992).

Energy: *MJth diesel energy*
Transport: *Gaslinetransport NL*

Data for the production of synthesis gas include the input of natural gas (35.2 MJ/m3) and energy from diesel.

Triple super phosphate

Record: IVAM
References: SPIN P-fertilizer (1992)

Inputs from technosphere: H_2SO_4 and P_2O_5
Energy: *MJel NL model (set: ETH+grid)* and *Steam (BUWAL 1991)*

Triple and Single super phosphate is co-produced. Allocation is based on mass. Resource inputs are phosphate ore, H_2SO_4 and P_2O_5. No data for the mining or transport of the ore is included.

Urea

Record: IVAM
References: EPA (1985), Longman et al. (1971) and SPIN N-Fertiliser (1995)

Input from technosphere: *Ammonia* and CO_2 (recorded as *Material known, no data*)

The inventory does not include energy use.

Energy – fuel

Coal B300

Record: A. De Beaufort
References: BUWAL 300

Data for precombustion of coal. The precombustion data are derived from the difference between the total and the "combustion only" emission factors. Based on the BUWAL 250 study and ETH/ESU study, 3. edition July 1996. Resources from nature are wood, energy from hydro power, lignite, coal, natural gas, crude oil, uranium (in ore) and undefined energy. Radioactive substances emitted to air and water are reported in kBq.

Crude lignite

Record: Pré Consultants
Reference: BUWAL 132 (1990)

Precombustion data for lignite. Inputs from nature are recorded as lignite and unspecified energy. Produc. waste (not inert) is recorded as solid emissions.

Diesel B

Record: Pré Consultants
Reference: BUWAL 132 (1990)

Diesel precombustion data. Resources from nature are crude oil and unspecified energy. Produc. waste (not inert) is recorded as solid emissions.

Diesel B300

Record: A. De Beaufort
References: BUWAL 300

Data for diesel precombustion. Based on BUWAL 250 and an ETH/ESU study edited in 1996. Resources from nature are wood, energy from hydro power, lignite, coal, natural gas, crude oil, uranium (in ore) and undefined energy. Radioactive substances emitted to air and water are reported in kBq.

Diesel changing load

Record: PRé Consultants
References: Boeijink (1993)

Energy: *Diesel B*

Diesel engine under continuos changing load. This process is in this study used for compaction at the landfill

Diesel (I) / Diesel Euro ’91 (ETH)

Record: IVAM
Reference: ETH Energy version 2 (1992)

Diesel (I) is just converting diesel in kg’s to l’s. Main primary source for the refinery are the Concawe-Reports (1979-1992), based mainly on questionnaires to W European refiners. Resource inputs reported are crude oil, natural gas, coal, water, silver and limestone. Data are aggregated and transports, electricity use etc are not separately reported.

Fuel gas (0.795 kg/m^3)

Record: IVAM
References: Ökobilanz von Packstoffen, Stand 1990 Schriftenreihe Nr. 132 Buwal 1991, Montfrans et al. (1988), Gasnummer No. 4 April (1992) and NOVEM (1992).

Energy: *MJth diesel energy*
Transport: *Gaslinetransport NL*

The fuel gas data are based on North European gas mining. The fuel gas is prepared using the raw material natural gas and energy from diesel.

Heavy fuel oil (0.95 kg/l)

Record: IVAM
References: ETH Energy version 2 (1994)

Input from technosphere: *Diesel Euro ' 91 (ETH)*

Light fuel oil (0.84 kg/l)

Record: IVAM
References: No source

Input from technosphere: *Diesel Euro '91 (ETH)*

LPG I

Record: Delft University of Technology
References: PWMI report 2 Olefins

Liquified gas. By-product of refinery process. Assumed to be equal to the production of general refinery products. LHV 24.4MJ/l=45.5MJ/kg. Source: IDEMAT 96. Inputs from nature are crude oil, iron, bauxite, coal, undefined energy and water. "Inorganic general" and slag is recorded as solid emissions and these fractions are not followed to the grave.

Natural gas B300

Record: A. De Beaufort
References: BUWAL 300

Precombustion data. Based on BUWAL 250 and an ETH/ESU study edited in 1996. Resources from nature are wood, energy from hydro power, lignite, coal, natural gas, crude oil, uranium (in ore) and undefined energy. Radioactive substances emitted to air and water are reported in kBq.

Oil for refinery

Record: IVAM
References: Bergh and Jurgens (1990), VROM Emission factors and Kunststoffe (1980)

Energy: *MJth ind energy (set ETH/CBS)*
Transport: *Oil line transport*

Emissions factors from Dutch producers and references. Solid waste is excluded from the inventory.

Oil heavy B300

Record: A. De Beaufort
References: BUWAL 300

Precombustion data. Based on BUWAL 250 and an ETH/ESU study edited in 1996. Resources from nature are wood, energy from hydro power, lignite, coal, natural gas, crude oil, uranium (in ore) and undefined energy. Radioactive substances emitted to air and water are reported in kBq.

Oil light B300

Record: A. De Beaufort
References: BUWAL 300

Precombustion data. Based on BUWAL 250 and an ETH/ESU study edited in 1996. Resources from nature are wood, energy from hydro power, lignite, coal, natural gas, crude oil, uranium (in ore) and undefined energy. Radioactive substances emitted to air and water are reported in kBq.

Open pit coal

Record: IVAM
References: BUWAL 132 (1990)

Energy: *MJel UCPTE model* and *MJth light fuel oil*
Transport: *Carriertransport*

The resource used is coal (29.3 MJ/kg).

Shaft coal

Record: IVAM
References: BUWAL 132 (1990)

Energy: *MJth gas energy, MJth heavy fuel oil* and *MJel UCPTE model*
Transport: *Railtransport*

The resource used is coal (29.3 MJ/kg).

Steam (BUWAL 1991)

Record: IVAM
Reference: BUWAL 132 (1990)

Input from technosphere: *shaft coal, open pit coal, light fuel oil (0.84 kg/l), heavy fuel oil (0.95 kg/l)* and *fuel gas (0,795* kg/m^3*)*

Data include only energy consumption and air emissions.

Wood FAL

Record: Sylvatica, North Berwick, Maine, USA
Reference: Franklin Associates (1998)

Inputs from nature are coal, natural gas, crude oil, uranium, wood and wood wastes and limestone. Solid waste not followed to the grave is reported.

Energy - heat

Heat diesel B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Data are aggregated. Including data on production and transport of primary energy sources, excluding the infrastructure of the energy systems. HHV.

Heat from coal IF

Record: PRé Consultants
References: ETH Energy version 2 (1994)

Data are aggregated.

Heat from gas IF > 100 kW

Record: PRé Consultants
References: ETH Energy version 2 (1994)

Data are aggregated.

Heat from heating oil

Record: fms/FOA
References: Miljöfaktahandok för bränslen

Energy: *Electr. hard coal*

Inputs from nature are crude oil, biomass, energy from natural gas, iron (ore) and coal. Slag/ash are recorded as solid emissions. The inventory data includes production and distribution of heating oil and usage of a district-heating plant. Swedish national average values for the heat-production has been used for a district-heating plant (gasification and combicycle) with a capacity of 50 to 300 MW. A sulphur content of 0,36 % in the heating oil is assumed.

Heat from natural gas

Record: fms/FOA
References: Miljöfaktahandok för bränslen

Energy: *Electr. hard coal*

Inputs from nature are natural gas, crude oil, biomass, wood, iron (ore) and coal. Slag/ash are recorded as solid emissions. The inventory data includes production and distribution of heating oil and usage of a district-heating plant. Swedish national average values for the heat-production has been used for a district-heating plant (gasification and combicycle) with a capacity of 50 to 300 MW.

Heat from oil IF S Euro

Record: PRé Consultants
References: ETH Energy version 2 (1994)

Data are aggregated.

Heat from resid. of timberf.

Record: fms/FOA
References: Miljöfaktahandok för bränslen, Vattenfall 1996 and Finnveden 2000.

Inputs from nature are biomass and crude oil. Ash is recorded as solid emissions. The inventory data includes collection, splintering, distribution and heat production of residues from timber felling during 1995 in Sweden. Assumed transport distance: 50 km. National average values for the heat production are used for a district-heatingplant (gasification and combicycle) with a capacity of 50 to 300 MW. The retrieval of the ashes to the forest or to a deposit is also included.

Heat oil (S, EU) B250

Record: Pré Consultants
References: BUWAL 250 (1996)

Energy content: 42.3 MJ/kg (HHV). Data include production and transport of primary energy sources, excluding the infrastructure of the energy systems. Data are aggregated.

Heat petrol B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Resources from nature are wood, pot. energy hydro power, lignite, coal, natural gas, crude oil and uranium (in ore). Radioactive substances emitted to air and water are reported in kBq. Includes detailed emission data for heat production from petrol in Europe, including production and transport of primary energy sources, excluding the infrastructure of the energy systems. HHV.

MJth coal energy

Record: IVAM
Reference: CBS (1992), VROM Emission factors (1993), IVEM energy (1992) and TNO/RIVM (1993).

Energy: *Open pit coal* and *Shaft coal*

Industrial combustion of 1 kg hard coal (steam quality) results in 29.3 MJ thermal
energy (NOVEM, 1992). Excluding basic metal, other metal industries and refineries,
including (indirect) CH_4, (direct) N_2O and PAH emission data for thermal combustion.
The average weighted transport distance is estimated at 6500 km by bulk carrier and 150 km by rail freight (IEA, 1992). No water emission data available.

MJth diesel (BUWAL)

Record: IVAM
References: BUWAL 132 (1990), IVEM Energy (1992) and VROM Emission factors (1993)

Input from technosphere: *Diesel (I)*

Emissions data derived from industrial combustion processes producing heat and electricity, assuming 100% heat production. Assumed average energy content of 42.5 MJ/kg.

MJth diesel energy

Record: IVAM
Reference: CBS (1992) and VROM/ER Emission factors (1993)

Input from technosphere: *Diesel (I)*

Same data as for light fuel oil burning are assumed. Light fuel oil has an energy content of 42.7 MJ/kg. Data are excluding basic metal, other metal and refineries.

MJth gas energy

Record: IVAM
Reference: CBS (1992) VROM/ER Emission factors (1993) and IVEM Energy (1992)

Input from technosphere: *fuel gas (0.795 kg/m^3)*

Basic metal, other metal industries and refineries are not included.

MJth heavy fuel oil

Record: IVAM
References: CBS (1992) and VROM/ER Emission factors (1993)

Input from technosphere: *Heavy fuel oil (0.95 kg/l)*

Data are excluding basic metal, other metal industries and refineries.

MJth light fuel oil

Record: IVAM
References: CBS (1992) and VROM Emissions factors (1993)

Input from technosphere: *Light fuel oil (0.84 kg/l)*

Data are excluding basic metal, other metal and refineries, including indirect CH_4 and direct N_2O and PAH emission data (from electricity production).

MJth ind energy IVAM ER

Record: IVAM
References: CBS (1992)

Input from technosphere: *Heavy fuel oil (0.95 kg/l)* and *Fuel gas 0.795 kg/m^3)*

The resource used is coal (29.3 MJ/kg). Data exclude (basic) metal and refineries.

MJth ind energy (set: ETH/CBS) / MJth ind energy ETH/CBS

Record: IVAM
References: ETH processes and CBS data

Energy: *Heat from coal IF 1-10 MW, Heat from gas IF > 100 kW, Heat from oil IF S Euro* and *Steam (BUWAL 1991)*

This model is set up to select industrial energy variant to be used. The one used here is MJth ind energy ETH/CBS. They provide average statistical data on energy carrier use by industry in general 1993-95. Energy carriers are coal, gas, oil and steam. For coal, gas and oil data used are recorded by PRé Consultants with reference to ETH (1994). These data are aggregated.

Energy- electricity

Electr. hard coal

Record: fms/FOA
References: Danish EPA (1998)

Marginal electricity production from hard coal. Data per MJ out from power pant. Efficiency of plant 47%. Lower calorific value of coal 24.3 MJ/kg. Data are aggregated. Radioactive emissions are recorded to air, water and waste.

Electr. coal UCPTE

Record: PRé Consultants and IVAM ER
References: ETH Energy version 2 (1994)

Detailed data on electricity production from coal in Europe (UCTPE), including capital goods, exploration of energy sources and transport. Power distribution system is not included. Emissions of landfill are not included, emissions of incineration and recycling are included. All radionucleides are aggregated to radioactive substances. A few substances of minor importance are left out. Data are aggregated.

Electr. gas UCPTE

Record: PRé Consultants and IVAM ER
References: ETH Energy version 2 (1994)

Detailed data on electricity production from gas in Europe (UCTPE), including capital goods, exploration of energy sources and transport. Power distribution system is not included. Emissions of landfill are not included, emissions of incineration and recycling are included. All radionucleides are aggregated to radioactive substances. A few substances of minor importance are left out. Data are aggregated.

Electr. hydro UCPTE

Record: PRé Consultants and IVAM ER
References: ETH Energy version 2 (1994)

Detailed data on electricity production from hydropower in Europe (UCTPE), including capital goods, exploration of energy sources and transport. Power distribution system is not included. Emissions of landfill are not included, emissions of incineration and recycling are included. All radionucleides are aggregated to radioactive substances. A few substances of minor importance are left out. Data are aggregated.

Electr. nuclear UCPTE

Record: PRé Consultants and IVAM ER
References: ETH Energy version 2 (1994)

Detailed data on electricity production from uranium in Europe (UCTPE), including capital goods, exploration of energy sources and transport. Power distribution system is not included. Emissions of landfill are not included, emissions of incineration and recycling are included. All radionucleides are aggregated to radioactive substances. A few substances of minor importance are left out. Data are aggregated.

Electr. oil UCPTE

Record: PRé Consultants and IVAM ER
References: ETH Energy version 2 (1994)

Detailed data on electricity production from oil in Europe (UCTPE), including capital goods, exploration of energy sources and transport. Power distribution system is not included. Emissions of landfill are not included, emissions of incineration and recycling are included. All radionucleides are aggregated to radioactive substances. A few substances of minor importance are left out. Data are aggregated.

Electricity from coal B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Inventory for 1 kWh electricity from coal, delivered from the network. Detailed data on electricity production from coal in Europe, including the energy use for the production of the coal and efficiency losses. Medium voltage. Data are aggregated. Radioactive emissions to air and water reported.

Electricity from gas B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Inventory for 1 kWh electricity from gas, delivered from the network. Detailed data on electricity production from gas in Europe, including the energy use for the production of the gas and efficiency losses. Medium voltage. Data are aggregated. Radioactive emissions to air and water reported.

Electricity from hydropower B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Inventory for 1 kWh electricity from hydropower, delivered from the network. Including efficiency losses. Medium voltage. Input from nature is potential energy from hydropower.

Electricity from lignite B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Inventory for 1 kWh electricity from lignite, delivered from the network. Detailed data on electricity production from lignite in Europe, including the energy use for the production of the lignite and efficiency losses. Medium voltage. Data are aggregated. Radioactive emissions to air and water reported.

Electricity from oil B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Inventory for 1 kWh electricity from oil, delivered from the network. Detailed data on electricity production from coal in Europe, including the energy use for the production of the oil and efficiency losses. Medium voltage. Data are aggregated. Radioactive emissions to air and water reported.

Electricity from uranium B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Inventory for 1 kWh electricity from nuclear power, delivered from the network. Detailed data on electricity production from nuclear power in Europe, including the energy use for the production of the uranium and efficiency losses. Medium voltage. Data are aggregated. Radioactive emissions to air and water reported

Electricity Holland 1993

Record: PRé Consultants and IVAM ER
References: ETH Energy version 2 (1994)

Energy: *Electr. coal UCPTE, Electr. oil UCPTE, Electr. gas UCPTE, Electr. hydro UCPTE, Electr. nuclear UCPTE* and *Steam (BUWAL 1991).*

The electricity model used is from BUWAL 250, that mix describes the 1993 situation. All the UCPTE electricity data are from ETH (1994) and include production data relevant for Europe. Data are aggregated and include capital goods, exploration of energy sources and transport. Emissions from landfilling are excluded, emissions from incineration and recycling included. All radionucleides are aggregated to radioactive substances.

Electricity Holland low V

Record: IVAM
References: ETH Energy version 2 (1994)

Energy: *Electricity Holland 1993*

Electricity Holland including 13,4% losses due to distribution and downscaling to 220 V (calculated percentage based on Swiss data). Also including main effects of distribution system (copper, lead and other ores used and inert final waste) according to EcoQuantum method, as calculated by including distribution losses in ETH UCPTE mix and subtracting this from UCPTE Low V. (including distribution system). Final waste (inert) is reported as solid emissions.

Electricity UCPTE B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Energy: *Electricity from coal B250, Electricity from gas B250, Electricity from hydropower B250, Electricity from lignite B250, Electricity from uranium B250* and *Electricity from oil B250.*

UCPTE electricity means the power network including the European countries excluding the British Isles. The mix thus obtained here gives the shares 17.4% electricity from coal, 7.4 % from natural gas, 16.4% from hydropower, 7.8% from lignite, 40.3% from uranium and 10.7%from oil. For each of the electricity sources production data are aggregated and obtained from the same reference.

Electricity without emission B

Record: PRé Consultants
References: BUWAL 132 (1990)

Fuels for European electricity production without emissions. This record is not to be used in an assembly or lifecycle. It is documented to be used in Buwal process trees in order to specify fuels. These data are used for *Pulp for cardboard B* which is in this study used in the virgin production of corrugated cardboard. The amount of pulp purchased is small compared to the biomass feedstock input and therefore the importance of the emissions excluded is small.

MJel gas Holland

Record: IVAM
References: CBS (1992), KEMA (1992) and IVEM Energy (1992)

Input from technosphere: *Fuel gas (0.795 kg/m^3)*
Transport: *Gaslinetransport NL*

Energy content of gas 35.2 MJ/m^3.

MJel NL model (set: ETH + grid) / Electricity Holland Low V

Record: IVAM
References: SEP/VEEN (1991), CBS (1992) and ETH (1996 and 1994)

Energy: *Electricity Holland 1993*

This model is set up by IVAM to select basic electricity variant to be used. The one used here is Electricity Holland Low V., which in turn is based on electricity Holland 1993 including 13.4% losses due to distribution and downscaling to 220 V.

MJel oil NL

Record: IVAM
References: CBS (1992), SEP/VEEN (1991), Oil and Gas Information 1989-1991 Données sur le pétrol et sur le gaz IEA (1992), VROM (1993) and Milieu 2 (1990)

Input from technosphere: *Heavy fuel oil (0.95 kg/l)*

No water emissions data provided. Energy content of heavy fuel oil assumed to be 41.0 MJ/kg, 0.95 kg/l.

MJel UCPTE model

Record: IVAM
References: BUWAL 132 (1990)

This electricity model is based on of 55.3% thermic energy, 32.3% nuclear power and 12.4% hydro power in 1988. The conventional energy is subdivided in 37.5% coal, 9.7% oil and 8.1% gas. Resource inputs are coal (29.3 MJ/kg), crude oil (41.9 MJ/kg), natural gas (35.2 MJ/m^3) and uranium in ore (336 000 MJ/kg). The average efficiency is 37.8% and data are including mining, transportation and processing of fossil and uranium fuel carriers.

Transport

Carriertransport

Record: IVAM
References: Marmé et al. (1982), Energiekentallen 1 (1992), BUWAL 132 (1990) and TNO/RIVM (1993)

Input from technosphere: *Diesel (I)*
Energy: *MJth ind energy IVAM ER*

Metal ores are usually transported in special bulk ore carriers. No specific emission data have been available. IVAM has derived data from sea transport emissions factors, including 12% of direct fuel for capital goods.

Diesel bus

Record: fms/FOA
References: Egebäck et al (1997) and Uppenberg et al (1999)

Data are aggregated.

Diesel ship (4-stroke)

Record: fms/FOA
References: Danish EPA (1998)

Data are aggregated. Radioactive emissions to air, water and waste are recorded. Industrial waste and hazardous waste from extraction not followed to the grave. Emissions in g/MJ of fuel (lower heating value 42.95 MJ/kg). Emission factors from CORINAIR (1996). Pre-combustion emissions from Frischknecht et al. (1994). The pre-combustion emissions are the same as for Diesel, heavy and medium truck. Fuel consumption 0.340 MJ/tonkm. CORINAIR (1996). The EMEP/CORINAIR Atmospheric Emission Inventory Guidebook (CORINAIR 90). Copenhagen: European Environment Agency. Frischknecht et al (1994). Ökoinventare für Energisysteme. Zürich: Bundesamt für Energiewirtschaft.

Diesel truck highway

Record: fms/FOA
References: Danish EPA (1998)

Data are aggregated. Radioactive emissions to air, water and waste are recorded. Industrial waste and hazardous waste from extraction not followed to the grave. Emissions in g/MJ of fuel (lower heating value 42.95 MJ/kg). Emission factors from CORINAIR (1996). Pre-combustion emissions from Frischknecht et al. (1994). Fuel consumption for medium sized truck (appr. 24 ton total) with full load (14.0 ton) corresponds to 0.00090 MJ/kgkm, 70% load (9.8 ton) 0.00119 MJ/kgkm, 50% load (7.0 ton) 0.00157 MJ/kgkm and 40% load (5.6 ton) 0.00191 MJ/kgkm.Fuel consumption for heavy truck (appr. 40 ton total) with full load (25.0 ton) corresponds to 0.00051 MJ/kgkm, 70% load (17.5 ton) 0.00067 MJ/kgkm, and 50% load (12.5 ton) 0.00087 MJ/kgkm. Fuel consumption for heavy truck (appr. 52 ton toatal) with full load (32.0 ton) corresponds to 0.00051MJ/kgkm, 70% (22.4 ton) 0.00065 MJ/kgkm, and 50% (16.0 ton) 0.00083 MJ/kgkm.

CORINAIR (1996). The EMEP/CORINAIR Atmospheric Emission Inventory Guidebook (CORINAIR 90). Copenhagen: European Environment Agency. Frischknecht et al (1994). Ökoinventare für Energisysteme. Zürich: Bundesamt

Diesel truck rural

Record: fms/FOA
References: Danish EPA (1998)

Data are aggregated. Radioactive emissions to air, water and waste are recorded. Industrial waste and hazardous waste from extraction not followed to the grave. Emissions in g/MJ of fuel (lower heating value 42.95 MJ/kg). Emission factors from CORINAIR (1996). Pre-combustion emissions from Frischknecht et al. (1994).Fuel consumption for medium sized truck (appr. 24 ton total) with full load (14.0 ton) corresponds to 0.00100 MJ/kgkm, 70% load (9.8 ton) 0.00132 MJ/kgkm, 50% load (7.0 ton) 0.00175 MJ/kgkm and 40% load (5.6 ton) 0.00212 MJ/kgkm.Fuel consumption for heavy truck (appr. 40 ton total) with full load (25.0 ton) corresponds to 0.00057 MJ/kgkm, 70% load (17.5 ton) 0.00075 MJ/kgkm, and 50% load (12.5 ton) 0.00098 MJ/kgkm. Fuel consumption for heavy truck (appr. 52 ton toatal) with full load (32.0 ton) corresponds to 0.00057 MJ/kgkm, 70% (22.4 ton)0.00072 MJ/kgkm, and 50% (16.0 ton) 0.00093 MJ/kgkm.

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Diesel truck urban

Record: fms/FOA
References: Danish EPA (1998)

Data are aggregated. Radioactive emissions to air, water and waste are recorded. Industrial waste and hazardous waste from extraction not followed to the grave. Emissions in g/MJ of fuel (lower heating value 42.95 MJ/kg). Emission factors from CORINAIR (1996). Pre-combustion emissions from Frischknecht et al. (1994). Fuel consumption for medium sized truck (appr. 24 ton total) with full load (14.0 ton) corresponds to 0.00112 MJ/kgkm, 70% load (9.8 ton) 0.00148 MJ/kgkm, 50% load (7.0 ton) 0.00196 MJ/kgkm and 40% load (5.6 ton) 0.00238 MJ/kgkm.Fuel consumption for heavy truck (appr. 40 ton total) with full load (25.0 ton) corresponds to 0.00063 MJ/kgkm, 70% load (17.5 ton) 0.00083 MJ/kgkm, and 50% load (12.5 ton) 0.00108 MJ/kgkm. Fuel consumption for heavy truck (appr. 52 ton total) with full load (32.0 ton) corresponds to 0.00063MJ/kgkm, 70% (22.4 ton) 0.00080 MJ/kgkm, and 50% (16.0 ton) 0.00103 MJ/kgkm. CORINAIR (1996). The EMEP/CORINAIR Atmospheric Emission Inventory Guidebook (CORINAIR 90). Copenhagen: European Environment Agency. Frischknecht et al (1994). Ökoinventare für Energisysteme. Zürich: Bundesamt

Electr. train

Record: fms/FOA
References: Danish EPA (1998)

Energy: *Electr. hard coal*

Electricity consumption 0.300 MJ/ ton km (from Tillman et al. 1991). Tillman et al (1991). Packaging and the Environment. Life-cycle analysis of selected packaging materials. Quantification of environmental loadings. Chalmers industriteknink. Gothenburg, Sweden.

Gaslinetransport NL

Record: IVAM
References: BUWAL 132 (1990)

Transport: *Railtransport* and *Truck (28 t ETH-V process)*

Input from nature is natural gas. Gas pipeline transport in the West European region uses special gasturbines with a specific energy requirement of 0.012 m3 gas per km per tonne gas [BUWAL, 1991]. Indirect emissions (CH4) are added in industrial combustion and electrical power plants data. Total energy consumption 0.42 kJth/kmkg. Tthe most important missing substances per kmkg are: 310 mg coal; 71,3 mg; 61 mg crude oil; 24 J from hydro power; 3 gram river sand; 7 gram water (all raw materials as inputs); and 1,6 gram CO2 airborne emission.

Oillinetransport

Record: IVAM
References: BUWAL 132 (1990), Montfrans et al (1989) and Ministry of Economic Affairs (1991).

Energy: *MJel oil NL*

Oil transport by pipeline requires an energy input of 0.0194 kWhe per km per tonne oil. The weighted average transport distance from North sea production platforms to Dutch refineries is estimated at 260 km (Ministry of Economic affairs, 1991). Oil production platforms on the North Sea are directly connected to oil refineries on land by special pipelines. Total energy consumption 0.175 kJth/kmkg.

Passenger car B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Energy: *Heat diesel B250* and *Heat petrol B250*

Road transport; per km; 20% diesel and 80% petrol. No goods, just passengers. Source ESU-ETHZ (1994).

Rail transport

Record: IVAM
References: BUWAL 132 (1990)

Energy: *MJth diesel energy* and *MJel UCPTE model*

Including capital goods (45% of direct fuel!). Total energy consumption0.48 kJth/kmkg.

Rivertransport

Record: IVAM
References: BUWAL 132 (1990)

Input from technosphere: *Diesel (I)*
Energy: *MJth ind energy (set: ETH/CBS)*
Including 12% direct energy use for capital goods.

Tractor 68 kW

Record: IVAM
References: INNAS Mobiele werktuigen, energieverbruiken emissies (1990) and Open University Road & R (1974)

Inputs from technosphere: *Diesel (I)*
Energy: *MJth ind energy (set: ETH/CBS)* and *MJel UCPTE model*
Data are a high estimate of specific fuel consumption, especially applicable for agricultural contractors.

Tractor I

Record: Delft University of Technology
References: Transport NL

Input from technosphere: *Diesel I*

Average data for 1 km with a tractor. Dutch situation 1989.

Tractor spreading

Record: fms/FOA
References: -

Transport: *Tractor 68 kW*

Energy used when spreading fertiliser on to field

Train (diesel & electric) B250

Record: PRé Consultants
References: BUWAL 250 (1996)

Energy: *Electricity UCPTE B250* and *Heat diesel B250*
Data describe average rail transport in Western Europe (1990-1994). 20% of the transport are with diesel locomotives. Production of fuels included.

Truck (28 t ETH-V process)

Record: IVAM
References: -

Input from technosphere: *Diesel (I)*

Truck 16e

Record: IVAM
References: Luchtverontreiniging emissies door wegverkeer 1978-1984, CBS: 1986; emissionfactors therein derived from from TÜV Rheinland: Das Abgas- Emissionsverhalten von Nutzfahrzeugen in der Bundesrepublik Deutschland im Bezugsjahr 1980/Umweltbundesambt-Berlin: Erich Schmidt Verlag, 1983, Berichte 11/83. N.A.Kohler: Analyse energetique de la construction..., these no. 623 EPFL Lausanne 1986. RIVM/ECN: Climate and energy: The feasibility of controlling CO2 emissions (ed. P.A. Okken a.o.) p.63, 1983. Open University Road/R (1974) and TNO/RIVM (1993)

Input from technosphere: *Diesel (I)*
Energy: *MJth ind energy (set: ETH/CBS), MJel UCPTE model* and *MJth heavy fuel oil*

Truck 16f

Record: IVAM
References: Open University Road R (1974)

Input from technosphere: *Diesel (I)*
Energy: *MJth ind energy (set: ETH/CBS), MJel UCPTE model* and *MJth heavy fuel oil.*

The data are including energy for capital goods and these amounts to 58% of direct energy consumption.

Other

Wastew. Treatment industry

Record: IVAM
References: Revisievergunning 1994 GB

Input from technosphere: *Quicklime, NaOH 50%, HCl* and P_2O_5

Data for treatment of $3*10^6$ m^3/yr industrial waste water, with a Carrousel-process.

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