Paper and cardboard — recovery or disposal?

Review of life cycle assessment and cost-benefit analysis on the recovery and disposal of paper and cardboard

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European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark
Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99
Web: www.eea.europa.eu
Enquiries: www.eea.europa.eu/enquiries

Preface

This report presents a review of existing environmental and economic studies covering alternative recovery and disposal options for waste paper and cardboard. The review process was divided into two sequential parts.

- A review of life cycle assessment (Part 1), carried out in 2003/2004
- A review of cost-benefit analysis (Part 2), carried out in 2004/05.

The two reviews can be read independently, whereas in this report an executive summary introduces them, gathering the conclusions from both reviews, and drawing some overall conclusions.

The report was prepared by European Topic Centre on Resource and Waste Management (ETC/RWM) and its preparation was guided by EEA project manager — Bartosz Zambrzycki

Members of two expert groups having prepared the reviews are listed below.

Life cycle assessment review

Alejandro Villanueva (project manager), ETC/RWM;

Matti Viisimaa, ETC/RWM;

Henrik Wenzel, Institute for Product Development, Denmark; and

Karin Strömberg, CIT Ekologik AB, Chalmers Industriteknik, Sweden.

Alejandro Villanueva and Henrik Wenzel were responsible for writing the review and drawing the conclusions, while Matti Viisimaa and Karin Strömberg assisted in the literature search and data collection.

Cost-benefit analysis review

Mette Skovgaard (project manager) and Ulf Moth Gilberg, ETC/RWM.

In addition, a steering group was set up with the purpose of providing guidance and comments on earlier versions of the report.

Niels Dengsøe, Danish National Research Institute and Aalborg University, Denmark.

Henrik Wenzel, Institute for Product Development, Denmark.

Hans Vos, European Environment Agency.

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REVIEW OF COST-BENEFIT ANALYSIS

1 Executive summary

To provide a solid basis for policies and policy-making in the field of waste management, the environmental and economic impacts caused by different waste treatment options should be examined. In recent years, a large number of studies comparing recycling with recovery or final disposal have been published, which are based on life cycle assessment (LCA) and cost-benefit analysis (CBA). To the frustration of policy-makers, experts and, not least the public at large, the results from these studies often differ greatly, and are even sometimes directly conflicting. Therefore, it would be of value to evaluate the robustness of these studies and their conclusions, and to clarify the reasons why results apparently differ so much. This is the overall purpose of the present project. Studies using LCAs and CBAs for comparison of waste management options for paper and cardboard have been reviewed.

1.1 Background

The thematic strategy on the prevention and recycling of waste

The communication by the European Commission on the thematic strategy was inspired by a life cycle approach to resources management taking waste phase as its starting point. Following this approach, waste prevention and recycling are assumed to reduce the environmental impact of resource use by avoiding negative environmental impacts arising at all stages in the life cycle of products. These impacts include extraction and initial processing, transformation and manufacturing, consumption or use and, finally, waste management.

The communication argues that in some cases questions arise as to why specific materials are addressed in one waste stream but not in others. For example, while Community legislation requires the recycling of paper and cardboard from packaging, there is no analogous requirement for paper from other sources, such as office paper or newsprint. Paper from these sources is often as appropriate for recycling from both an economic and environmental point of view.

On this basis, the potential advantages of setting material-based recycling targets rather than product-based recycling targets should be examined. 'Paper and cardboard' is given as an example of a material to which such logic could be applied. The input to such target-setting could, for instance, be supported by information from both LCAs and CBAs.

Instead of conducting further analysis, the European Commission requested the EEA and its Topic Centre on Waste and Material flow (now renamed the Topic Centre on Resource and Waste Management) to undertake two reviews of already existing studies in order to analyse whether any conclusions could be drawn on preferable waste management options for paper and cardboard. Thus, the present report has been prepared as an input to the process of elaborating the thematic strategy on the prevention and recycling of waste.

Objective

Two separate reviews have been carried out covering studies of alternative recovery and disposal options for paper and cardboard: one for LCAs and one for CBAs.

The objective has been to identify and subsequently to perform critical analysis of the LCA and CBA studies. The aim is also to identify and assess the system parameters and boundary assumptions that have been most decisive for the conclusions obtained in the studies analysed.

This approach has been chosen because there are many methodological issues involved in carrying out an LCA or CBA study; all of which can have a strong influence on the outcome of the study. Such methodological issues comprise, for example, the goal and scope of the study, definition of the system boundaries, weighting, environmental impact categories selected or monetary values chosen.

The role of decision support tools

A wide spectrum of tools can be used to support decisions in the environmental field; two of the most discussed are LCAs and CBAs. These tools have different areas of applicability, different advantages and disadvantages, and their suitability depends on the type of problem to be assessed. LCA is based on natural science while CBA is based on welfare economics. Thus, even though LCA and CBA pursue the same goal of comparing waste management alternatives, they cannot answer the same question. LCA expresses environmental impacts, whereas CBA expresses economic impacts.

An important difference between LCAs and CBAs is the degree to which the methods have been standardised. Although CBAs have existed as a tool for decades, no standard has been developed to ensure a uniform application. In contrast, between 1997 and 2000 the International Standardisation Organisation (ISO) published a series of standards which now serve as a guideline for conducting LCAs. As a result, CBAs are considerably more heterogeneous than LCAs in terms of the choice of system boundary and methodology.

None of the tools should serve as the sole basis for a decision, since individually they are not able to bring forward all relevant aspects of a proposed project. Instead of being considered as competing, LCA and CBA should be seen as complementary.

1.2 Summary of the LCA review

Scope

A total of nine LCA case studies, containing 73 scenarios, have been selected from a thorough literature search. The selected studies are primarily LCAs including different management options for waste paper and cardboard.

The nine studies have been selected on the basis of a combination of selection criteria defining their quality and comprehensiveness. These criteria include: compliance with international LCA methodology standards, the perspective adopted by the study (company/society), the time frame (long-term/short-term), the year of the study and the type of paper/cardboard.

The impact categories for the environmental assessment of paper systems used in this review, representing the scope of categories contained in the analysed LCAs, are:

- energy use (or generation);
- resource consumption;
- energy-related impacts (e.g. acidification, greenhouse effect);
- toxicity (of emissions);
- waste generation;
- wastewater.

The analysis encountered some difficulties of a non-technical nature. Legislative differences were one area of difficulty. For example, some of the residues from incineration (gypsum, slag and ashes) are currently characterised and registered as waste in the EU Member States, whereas they are classified as by-products in some countries outside the EU. When such differences exist, there is a question of comparativeness. Can the waste generation of two systems from two different countries be compared?

Methodology-related issues

The paper system is complex. The life cycle of paper is characterised by a number of system parameters and system boundary assumptions that not all LCAs include. These parameters and assumptions should cover all essential activities/processes in the technosphere affected by the choice. These parameters include secondary services such as generation of energy from wood residues and paper incineration, forestry services and parallel services provided by the existing waste management systems. LCAs should, as far as possible, include such services in order to describe correctly the environmental impacts occurring when choosing one alternative over the other. These parameters and assumptions are needed to ensure that the systems to be compared are actually fully comparable.

The LCA review has included a systematic exploration of the key system boundary criteria that can have an influence on the result of a life cycle assessment of paper. This exploration has resulted in the identification of 15 key assumptions that cover the three paper cycle system areas of: raw materials and forestry, paper production and disposal/recovery. The key assumptions are presented in the box below.

Results of the reviewed studies

The results of the 73 scenarios have been classified and presented as a function of the 15 key assumptions identified. The outcome of the individual LCA studies largely depends on the choices made in some of these assumptions; the most important being connected to the geographical conditions of the region analysed.

Nevertheless, the results from the nine LCA studies, produced in different geographical areas and including in different degrees the key assumptions mentioned, all indicate that recycling results in less overall environmental impacts than both landfilling and incineration. These geographical differences are not large enough to result in incineration or landfilling being more favourable. The result is clear in the comparison of recycling versus landfilling, and less pronounced, but also clear, in the comparison of recycling versus incineration.

It is theoretically possible that geographical regions exist, where incineration may be a better alternative than recycling from an environmental point of view. However, no such case has been found in the LCA studies reviewed.

15 key system boundary parameters

1. Is the alternative use of land/wood included?
2. Is the saved wood used for energy production?
3. Is wood considered a scarce resource?
4. Which is the marginal energy source for the electricity used in virgin paper production?
5. Which is the marginal energy source for the heat (steam) used in virgin paper production?
6. Which is the marginal energy source for the electricity used in recycled paper production?
7. Which is the marginal energy source for the heat (steam) used in recycled paper production?
8. Is the energy export from virgin paper production included?
9. Which is the main alternative to recycling: incineration or landfilling?
10. Are the emissions from paper landfilling included?
11. Does the thermal energy produced from incineration substitute other sources?
12. Does the electricity produced from incineration substitute electricity from the grid?
13. Are the alternative uses of incineration and landfilling capacity included?
14. In which ratio does recycled paper substitute virgin paper?
15. Is the handling of rejects and de-inking waste from paper recovery?

Life cycle assessment (LCA) technique[1]

Life cycle assessment is a 'cradle-to-grave' approach for assessing the environmental impact of a single product or system. An ideal LCA should include all stages in the product life cycle from the gathering of raw materials for production through to the point where all waste materials and emissions are returned to the earth (or air or water). The total cumulative environmental impacts resulting from the product can thus be estimated by summing the environmental impacts from each element of the total system.

The LCA process consists of four components:

- Goal Definition and Scoping — the objective and audience of the LCA are identified. A functional unit is defined which describes the basic function of the product, process or activity (e.g. disposal of 1kg of waste paper). Quality requirements are defined for input data, and finally boundaries of the system to be studied are set (i.e. which unit processes and subsystems should be included in the total assessment).
- Inventory Analysis — the identification of all raw inputs and outputs into and from the system, i.e. inputs such as energy, water and materials usage and outputs such as air emissions, solid waste disposal, wastewater discharge.
- Impact Assessment — the inputs and outputs into the full system as listed in the Inventory, are further reduced to a number of key impact categories. These might include global warming effect, ozone depletion, human toxicity, ecological toxicity, non-renewable resource use etc. Each impact category will have a set unit, usually equating to the impact of a standard emission e.g. greenhouse gas effect might be given in units of 'tonne CO_2 equivalent'.
- Interpretation — the results of the inventory and/or impact assessment stages are interpreted in order to identify the better performing product among a number of alternatives assessed. A clear understanding of the uncertainties inherent in the results is necessary for this element. The interpretation stage is the most subjective element of an LCA since it often requires decisions to be made on the relative importance of various impact categories.

[1]) ISO standards for LCA up to the impact assessment stage were published in 1997.

It is also interesting to observe that the results in certain environmental impact categories are more unambiguous than in others with respect to the choice made in the key assumptions. 'Energy use', 'Energy-related impacts' and 'Wastewater' results are clearer than 'Resource consumption' and 'Waste generation' results.

The results obtained refute one of the hypotheses motivating the present study, namely that the results of existing paper LCA studies are very different. Generally, the LCA studies analysed, which were selected from existing literature on the basis of a set of quality criteria, arrive at similar results. Some differences are observed, however. These differences are not found primarily to be due to actual differences in the environmental impacts from the paper systems studied, but rather to differences in the way the LCA methodology is applied. This is especially the case with the definition of the paper system and its boundaries. The differences observed in some of the studies, therefore, are not believed to be the result of conscious methodological choices.

1.3 Summary of the CBA review

Scope

A total of nine studies containing 41 scenarios are included in the review: seven cost-benefit-type studies on paper; one cost-benefit-type study on municipal waste, where paper is a separate waste fraction; and one life cycle assessment, where the externalities have been subject to monetary valuation. Only two studies were conducted for direct policy support, while the rest have focussed on contributing to the policy debate.

The hypothesis assumed from the outset of the review was that a lot of cost-benefit analyses exist on paper and that it would be possible to gain some general insight from these studies. Surprisingly, the literature inventory only identified a few studies that can be characterised as cost-benefit-type studies on paper, cardboard and paper packaging.

For this reason, a pragmatic selection took place. Studies were selected which included an economic and environmental assessment of alternative treatment options. These studies were transparent in terms of the assumptions and results achieved, and focused on paper/cardboard packaging rather than packaging in general. Moreover, they were European. The studies were all published in the nine-year period of 1994–2002.

The review does not allow conclusions to be made as to the optimal socio-economic level of recycling, incineration or landfilling. Such conclusions are highly dependent on case-specific conditions such as paper type, treatment capacity, transportation distance and prices. Furthermore, the studies do not cover these issues in sufficient detail.

Methodology-related issues

Four guidelines on CBAs from European countries and international organisations have been used to identify six basic CBA steps which form the reference point. A set of criteria was defined on the basis of these steps, and together with the system boundary issues identified in the LCA review, has been used as the basis for the CBA review.

None of the reviewed studies fully applies the basic steps for conducting a CBA. In particular, discounting is avoided in seven of the eight CBA-like studies. One study does not include the monetary valuation but lists environmental and economic conclusions separately.

Few studies have included a description of the 15 key system boundary criteria from the LCA review. Only two of the nine CBA studies include half or more of the 15 system boundary criteria, while the remainder of the studies includes less that half. The limited coverage of the life cycle of paper in the reviewed CBA studies is also illustrated by the number of externalities, or emissions, included in the studies. They vary from 2 to 28 whereas more than half of the studies include around 10 externality parameters.

The parameters that are most decisive for the conclusions of the reviewed studies are:

- time cost;
- waste paper price;
- total external costs;
- system boundary.

The time cost represents the value of private households time spent on sorting and transporting waste paper to recycling facilities. Households are assumed to spend between 15 and 30 minutes per week on this activity. The high cost of this activity turns out to be decisive for the conclusion in three of the five scenarios considering this issue.

The waste paper price typically represents the economic benefit of the recycling activity. However, the market price for waste paper fluctuates considerably, which is why it is a source of uncertainty in a cost-benefit analysis.

In some studies, the total external costs influence the conclusions due to their significantly high values compared with other costs. Unfortunately, the environmental assessment in most of the studies is poorly described. Therefore, it is not possible to specify which the essential environmental parameters are. Nevertheless, it is clear that most of the studies include the traditional air emission parameters from energy production (incineration).

Although the review does not lead to any firm conclusion regarding the choice of system boundary, this choice is still perceived to influence the outcome of a study. The review shows that there are large variations in the system boundaries and the degree to which different elements of the paper system are included. By excluding the upstream elements such as 'avoided virgin paper processing', the potential benefits of recycling are excluded. Moreover, the review shows that the system boundary in the environmental assessment and the economic assessments of a study are not always the same.

Results of the studies reviewed

In the review, 18 conclusions are reported from the nine studies. The number of conclusions is higher than the number of studies because some studies analyse either several waste paper fractions or the sources of collection or they apply more valuation methods for estimating the external cost. More than half of the conclusions find that recycling is the preferred waste management option. Incineration and/or landfill are preferred in the remaining studies and scenarios. If the time cost is excluded, the preference for recycling becomes more explicit.

The nine studies differ extensively with regard to both system boundaries and methodology for assessing the environmental and economic impacts. Due to the limited number of studies and too few studies including the same parameters or applying the same system boundary, it is not possible to draw conclusions concerning a preferable option of waste paper management.

The present review concludes that there is room for improvement in the methodology currently used in waste paper CBAs , regarding improved transparency, improved economic methodology to derive prices, and the use of a more consistent system boundary. There is a need for supplying CBA analysts with more thorough guidance on how to conduct system analysis in connection with cost-benefit studies. Inspiration could, for instance, be found in LCA guidelines.

1.4 Overall conclusion, LCA and CBA reviews

The LCA review concludes that the majority of LCAs indicate that recycling of paper has lower environmental impacts than the alternative options of landfill and incineration. The result is very clear in the comparison of recycling with landfilling, and

Cost-benefit analysis (CBA) technique

Cost-benefit analysis is a decision-support tool which helps decision makers to develop policies providing the highest environmental benefits at the lowest overall cost to society. The CBA method attempts to place a monetary value on the environmental and social impacts of a policy, and add them to its commercial costs. The combined 'present value' cost to society can then be equated with the combined cost of an alternative policy.

Six basic CBA steps can be identified:

1. Formulation of the problem/definition of the CBA
2. Description of consequences (scope definition)
3. Monetary valuation
4. Discounting
5. Evaluation (net present value (NPV) and conclusion)
6. Evaluation of uncertainty

The scope of a CBA study is potentially much greater than that of an LCA study which only compares environmental impacts. An ideal CBA would include a full LCA up to the impact assessment stage, as just one element of the scope. No international standards exist for the CBA technique.

less pronounced, but still clear, in the comparison of recycling with incineration.

The CBA review concludes that in little more than half of the CBAs, paper recycling has higher socio-economic benefits than other management options. In the remainder of the studies, the socio-economic benefits of incineration, landfill or other options are higher than those gained from recycling. It is often said that CBAs are generally favourable to other waste management options than recycling. However due to the heterogeneity of the methodologies used in the reviewed CBAs, it is not possible to confirm or to reject this statement.

These conclusions should be interpreted having in mind the potential and limitations of the LCA and CBA methodologies. Both methodologies involve a series of assumptions enabling the comparison of two or more waste paper treatment options which otherwise would not be comparable. The paper system is complex. It has been found that the necessary assumptions made about the definition of the system borders and the choices about which indirect effects (e.g. energy production from incineration of paper) are included or excluded from the system are decisive for the outcome of an LCA or CBA.

With LCAs, the existence of an internationally agreed procedure, including the requirement of transparency in the calculations, allows the identification of those assumptions most important for the outcome. The CBA methodology has so far not reached such a level of international agreement about the stages to be followed. Moreover, most studies are not transparent. Therefore, it has not been possible to identify the most relevant background assumptions and their possible correlation with the outcome of the CBA studies. This study has shown, however, that some of the important assumptions concern system analysis and system boundaries definitions.

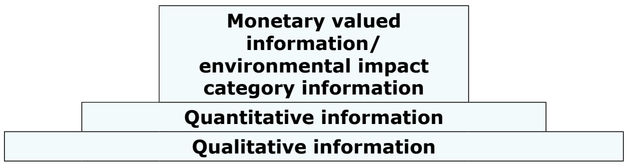
Drawing from the experience of this review, it seems necessary to further develop CBA guidelines. This would greatly help policy-makers to take informed decisions based on results deriving from this tool.

Use of the results for policy support

One of the objectives of this review is to inform European policy-makers as to whether the individual LCA and CBA studies on this topic gave conclusions pointing in the same direction. It has been shown that there is a clear answer from LCAs, but not from CBAs. A clear answer is, however, not sufficient for a direct transfer to policy-making. When using LCAs and CBAs for decision-making, three main issues should be considered:

a) loss of available information;
b) differences in geographical scope;
c) the ability to use national studies — especially CBAs — for supranational policy-making.

Ad a) When considering the decision-support value of CBAs and LCAs, it becomes evident that much qualitative information exists and has to be interpreted. Only a proportion of this information can be quantified, and only a proportion of the quantified information can be ascribed either a monetary value (CBA) or an environmental impact category (LCA). An information pyramid illustrates this process where the information available is selected and structured in a form suitable for decision-making support.



Source: Adapted from Hjerp *et al.* 2005.

LCA and CBA methodologies are two of the best available decision support tools, but it still has to be borne in mind that they operate with imperfect information.

Ad b) Concerning geographical scope, while the CBA is undertaken most often at regional or national level, it is often the ambition of an LCA to address environmental issues on a global scale. The environmental assessment of an LCA typically has a broader scope, and even impacts that may take place outside the country are accounted. This serves to illustrate the difference between the two approaches. However, in the reviewed CBAs the environmental assessment often takes a broader scope than the national one.

Ad c) Even if several national CBAs show a clear, common answer, it is important to point out that policy-makers should be cautious in extrapolating the conclusions to supranational policy objectives. Any CBA on waste paper is conducted using a geographical reference, for example, a locality, region or State. Specific information from these areas is used as input to the studies, and as a result their conclusions are tailored to support policies and targets of that area.

As most CBAs are national in scope, they analyse which waste management alternative option provides the socio-economically preferable solution within the national boundaries. When the system boundary is national, the CBA describes the costs and benefits within the national border. Consequences beyond the border are either ignored or not directly part of the costs and benefits. CBAs typically provide information about the costs and benefits of marginal effects on the market covered by the system investigated. Thus, the sum of national marginal changes within the EU may not necessarily be equal to a beneficial marginal change at EU level. In other words, making the same policy initiatives at European level based on national CBAs can lead to substantial effects on the market, such as changes in prices and market structures. These may not necessarily be socially beneficial in the long run. Due to the broader scope, LCAs, in particular, are more immune to such a generalisation of results when addressing environmental issues at regional or global levels.

Taking all the three issues into account, it is important that policy-makers who intend to use of LCAs and CBAs in decision making are aware of and take into account both the advantages and the possible problems and limitations of these tools.

REVIEW OF LIFE CYCLE ASSESSMENT

European Environment Agency

Summary

The present study has been prepared by the European Topic Centre on Waste and Material Flows (ETC/WMF) for the EEA and the European Commission as input to the process of elaborating the thematic strategy on the prevention and recycling of waste.

Policies on waste management can benefit from a clarification of the environmental impacts derived from different waste treatment options. It is therefore valuable to evaluate the robustness of the results from various — sometimes conflicting — life cycle assessment (LCA)-based and cost–benefit analyses (CBA)-based studies that have been published on recycling and comparisons of recycling with other recovery or disposal options.

This study focuses on paper and cardboard as waste materials.

The objective of the present study has been to identify and subsequently to make a critical review of existing LCA studies covering alternative disposal/recovery options for paper and cardboard. It has also been the aim of the study to identify and assess the system parameters and boundary assumptions that have been most decisive for the conclusions obtained in the LCA studies analysed, since there are many methodological issues involved in carrying out such a study. Variations in the outcome of an LCA can be due to methodological issues (e.g. LCA goal and scope definition, definition of the system boundaries, weighting, impact categories selected) or determined by the geographical characteristics/constraints of the region covered by the LCA.

A total of nine LCA case studies containing altogether 73 scenarios have been selected from a thorough literature search. The selected studies are primarily comparative LCAs including different management options for waste paper. The nine studies have been selected on the basis of a combination of selection criteria, including, for example, compliance with international LCA methodology standards, the perspective adopted by the study (company/society), the time frame (long term/short term), the year of the study, and the type of paper/cardboard.

The life cycle of paper is characterised by a number of system parameters and system boundary assumptions, which not all LCAs include. These parameters and assumptions should cover all essential activities/processes in the technosphere affected by the choice, including secondary services such as generation of energy from wood residues and paper incineration, forestry services, and parallel services provided by the existing waste management systems. Comparative LCAs should, as far as possible, include such services in order to describe correctly the environmental consequences occurring when choosing one alternative over the other. These parameters and assumptions are needed to ensure that the two or more systems to be compared are actually fully comparable.

The present project has included a systematic exploration of the key system boundary criteria that can have an influence on the result of a comparative paper LCA. This exploration has resulted in the identification of the following 15 key assumptions, that cover the three paper cycle system areas of raw materials and forestry, paper production, and disposal/recovery.

1. Is the alternative use of land/wood included?
2. Is the saved wood used for energy production?
3. Is wood considered a scarce resource, and what is then the wood marginal?
4. Which is the marginal energy source for the electricity used in virgin paper production?
5. Which is the marginal energy source for the heat (steam) used in virgin paper production?
6. Which is the marginal energy source for the electricity used in recycled paper production?
7. Which is the marginal energy source for the heat (steam) used in recycled paper production?
8. Is the energy export from virgin paper production included?
9. Which is the main alternative to recycling: incineration or landfilling?
10. Are the emissions from paper landfilling included?
11. Does the thermal energy produced from incineration substitute other sources?
12. Does the electricity produced from incineration substitute electricity from the grid?
13. Are the alternative uses of incineration and landfilling capacity included?
14. In which ratio does recycled paper substitute virgin paper?

15. Is the handling of rejects and de-inking waste from paper recovery included?

The results of the 73 scenarios have been classified and presented as a function of the 15 key assumptions identified. The overall results of the LCA studies indicate that recycling of waste paper has a lower environmental impact than the alternatives of landfilling or incineration. The result is very clear in the comparison of recycling versus landfilling, and less pronounced but also clear in the comparison of recycling versus incineration.

The results obtained refute one of the hypotheses motivating the present study, namely that the results of existing paper LCA studies were very different. The LCA studies analysed, selected from existing literature on the basis of a set of quality criteria, to a wide extent arrive at similar results. Some differences are observed, however. These differences are not found to be due to actual differences in the environmental impacts from the paper systems studied, but rather to differences in the applied LCA methodology and especially the definition of the paper system and its boundaries. The differences observed in some of the studies, therefore, are not believed to be the result of conscious methodological choices, but rather to unawareness about the need to include and justify certain assumptions in a comparative LCA.

The outcome of comparative LCAs on paper depends on the choices made in some of the 15 key assumptions identified. The most important of these assumptions are the following.

- The assumption of the energy and material marginals for wood, and the alternative uses of wood and forest land. **If** an alternative use of wood other than the use for paper production is included in an LCA, making wood a priority resource with a fossil fuel marginal, all LCA studies analysed show preference to paper recycling no matter what other assumptions were made.

- The assumption of the electricity marginal for virgin paper production. **If** the electricity used for virgin paper production is assumed — as in almost all cases it should be — to be based on fossil fuel and not hydropower, the vast majority of the analysed LCA studies show that paper recycling is more favourable than both landfilling and incineration.

- The assumption of substitution of electricity from incineration of paper. **If** it is assumed that no electricity is produced at waste incineration plants and accordingly electricity does not substitute electricity from the grid, paper incineration almost never turns out to be favourable.

- The assumption of alternative use of incineration capacity. **If** it is assumed that an increase of paper recycling releases some incineration capacity, and it is assumed that this capacity is used to incinerate waste that would otherwise have been landfilled, then in almost all cases analysed this implies that the results of the LCA are in favour of paper recycling.

LCAs on paper depend on a series of data that are linked to the geographical conditions of the region analysed. It is estimated that most geographical boundary conditions that can potentially influence the result of an LCA, are included in one or more of the 15 assumptions mentioned. The most essential geographical conditions are:

- geographical differences in the alternative use of the forest, its land and the residues from wood extraction;
- geographical differences in the sources of energy for electricity and heat production and the energy marginal;
- geographical differences in waste management practices.
  Specific examples of these are:
  (1) incineration/landfill capacity;
  (2) energy (heat, electricity) use from waste incineration;
  (3) collection of landfill gas and energy generation.

Nevertheless, an important conclusion from the present study is that the results from the nine studies, produced in different geographical areas, and including to different degrees the key assumptions mentioned, indicate that recycling results in less environmental impacts than both landfilling and incineration. It is not an excluded hypothesis that a location may exist where the combination of energy supply marginals (and not only averages) is such that incineration is overall a better alternative than recycling from an environmental standpoint. However, no such case has been found in the LCA studies reviewed.

The impact categories for the environmental assessment of paper systems used in this study, representing the full scope of categories contained in the analysed LCAs are:

- energy use (or generation)
- resource consumption
- energy-related impacts
- toxicity (of emissions)
- waste generation
- wastewater.

The environmental impact categories which are most clearly in favour of recycling are 'energy use', 'energy-related impacts' and 'wastewater'. Other impact categories where the picture is still favourable to recycling, however not as markedly, are 'use of resources', 'waste generation' and 'toxicity'.

It is also interesting to observe that the results in certain environmental impact categories are more robust than in others with respect to the choice made in the key assumptions. 'Energy use', 'energy-related impacts' and 'wastewater' results are more robust than 'resource consumption' and 'waste generation' results.

The robustness of 'energy use' is explained by the fact that energy data are mainly dependent on the type of technology used, and not on the key assumptions of system definition and boundary conditions.

'Resource consumption' and 'waste generation' are categories whose results are very dependent on the fuel mix used for producing the energy that is used in the virgin paper and recycling systems. The results in these categories can be slightly favourable to incineration if wood is used as fuel for virgin paper production and simultaneously coal is used as the only fuel for recycled paper production. Additional uncertainty is generated in some cases by the difficulty of obtaining reliable data about waste and resource use.

The impact category 'toxicity' is only included in very few scenarios. Therefore, the information about this category has not the same statistical value as the results from the other impact categories where information from most scenarios exists.

Additional difficulties for a comparison can be of non-technical nature, for example, legislative: the residues from coal combustion (gypsum, slag and ashes) are currently characterised and registered as waste in the EU countries, whereas they are by-products in other countries outside the EU. Such differences make the comparison of environmental profiles in these categories more difficult.

A general screening of some non-LCA studies, including several CBAs, has also been carried out. The studies included in the screening have different objectives, starting points, and very different methodologies. Compared with the conclusions observed in the LCAs, the results from these non-LCA studies are more spread than the LCAs. Some studies seem to be in favour of recycling, some in favour of incineration. The authors of these studies often find no absolute justification for recommending any particular management option, when taking into account also financial variables of waste management and incorporating environmental costs and benefits in their analyses. Few studies make categorical conclusions about the issue, and most of them arrive at soft conclusions, very dependent on the set of assumptions taken.

The methodological difficulties are reflected in the fact that a majority of the studies acknowledge the current limitations of the environmental economic tools used as a basis for decision support, and focus on a description of the uncertainties and the boundary conditions rather than on the result.

It is suggested as a challenging future activity to complete the literature list of non-LCAs collected in the present study, and investigate in detail the results and methodological implications of these non-LCAs, in a similar way to the activities carried out with the LCAs.

1 Introduction

1.1 Background

The present study has been prepared by the ETC/WMF for the EEA and the European Commission as an input to the process of elaborating the thematic strategy on the prevention and recycling of waste.

The communication, COM(2003) 301 from the European Commission, 'Towards a thematic strategy on the prevention and recycling of waste' is inspired by a life cycle approach to resources management and takes the waste phase as its starting point. It is assumed that waste prevention and recycling can reduce the environmental impact of resource use in two ways:

- reducing the use of resources (renewable and non-renewable) and the environmental impacts related to its use/depletion (resource, material and/or energy source loss);
- avoiding side environmental impacts arising at all stages in the life cycle of the resource, including extraction and initial processing, transformation and manufacturing, consumption or use and, finally, waste management.

The use of recycled materials is one factor, among others, which affects the life cycle performance of products. The European Commission has in its communication discussed the potential advantages of setting material-based recycling targets rather than product-based recycling targets. Paper is given as an example of a material to which such logic could be applied. In the communication, the Commission has also made clear that life cycle assessments (LCAs) and cost–benefit analyses (CBAs) are two methodologies that should be used as a basis for policy-making.

The Community legislation, under the directive on packaging and packaging waste, requires recycling of paper and cardboard from packaging, but there is no analogous requirement for paper from other sources, e.g. office paper or newsprint. Paper from these sources is often at least as appropriate for recycling from both an economic and environmental point of view. Paper/cardboard is also subject to a voluntary commitment by industry to increase the level of recycling. However, there is considerable debate on the relative environmental advantages and disadvantages of recycling, composting and energy recovery of paper/cardboard. This debate is expected to develop further in the framework of the discussions on the communication, and there is a need to clarify the relevance of the various sometimes conflicting LCA-based and CBA-based studies that have been published on recycling of paper and comparison of recycling with other recovery or disposal options.

1.2 Objective and scope of the study

The objective of the present study is to identify and to make a critical analysis of existing studies covering alternative disposal/recovery options for paper and cardboard, including, for example, material recycling, substance recycling, energy recovery, and landfilling.

It is also a part of the study to identify and assess the parameters that have been most relevant for the conclusions obtained in the LCA studies analysed. A priori, these parameters can be methodological (e.g. LCA goal and scope definition, definition of the system boundaries, weighting, impact categories selected) or determined by the geographical characteristics/constraints of the region where the LCA is made.

The project analyses existing LCA case studies and also other 'studies of studies' that review/compare existing LCA studies. In the literature screening, other relevant studies using non-physical units as a reference (e.g. CBAs) have also been collected. These studies have not been analysed in detail in the present study, but their role as a complement to LCAs in decision-making is discussed in the conclusion and outlook section. It is expected that an in-depth study of the CBAs on paper can be carried out in a later phase of the project.

1.3 Main activities carried out in the study

The study carried out consisted of the following activities.

1. Inventory of existing studies on the management of used paper, belonging to the following categories:

1.1 LCA studies on paper and/or cardboard
1.2 Reviews and comparative analyses of other LCA studies on paper/cardboard
1.3 Other life cycle-based environmental studies
1.4 Other life cycle-based studies using units other than physical for the comparisons, e.g. CBAs.

2. Definition of a set of criteria to be used in the selection of a group of 5 to10 studies from the studies collected in Activity 1.1. The final number of studies analysed is nine.
3. Using the knowledge of the reviews from Activity 1.2, definition of a set of analysis criteria to be used in the in-depth assessment of the selected studies. Use of these criteria for the in-depth assessment of the nine selected studies.
4. Identification of the key issues forming the framework for the comparative assessment, that is, the parameters that have been most relevant for the conclusions obtained in the LCA studies analysed, and which are the reason for the conclusions obtained. Discussion of the results.

2 Inventory of existing studies

2.1 Literature basis

The starting point for the elaboration of the present report is a thorough search of the existing literature on the life cycle of virgin paper and recycled paper fibres. A large number of studies have been published on this issue, mainly in the early and mid-1990s, and most of them in Europe. The publication of such studies has continued in the late 1990s and after 2000, but the methodology used in them seems to have switched slightly from being purely environmental studies (LCA included) in the mid-1990s towards combined environmental-economic studies in the late 1990s and after 2000.

Perspective of the studies

The studies found adopt different perspectives, depending on the target group and the decision that they are to support. Among the studies collected, two perspectives are relevant for the present study.

A **society perspective**. The studies using a society perspective are elaborated for assisting policy-makers in the selection of the best strategies for the management of used paper.

A **company perspective**. Some studies adopt the perspective of one or more paper industries (pulp production, paper/cardboard production, recycled paper production), and their goal is to support internal environmental improvements, e.g. reduction of emissions, optimisation of energy use, adoption of best available technologies, environmental management system compliance, and so on.

Methodology used in the studies

The methodological approaches of the studies also differ, but most of the studies fall within two categories:

- environmental studies using physical units as magnitude for the comparisons, mainly LCA and life cycle-based studies;
- economic-environmental studies using non-physical units (e.g. monetary) as a reference. These studies are mostly CBAs, but also life cycle cost studies.

A simplified classification of the studies found is presented in Table 2.1. The complete list of references collected is detailed in Annex 1.

2.1.1 Contacts

In order to make the list of existing studies as complete as possible and in addition to the literature search, a series of more than 60 companies, institutes, organisations, and universities in 12 European countries have been contacted and requested to contribute with relevant references. The complete list of institutions is presented in Annex 2.

2.1.2 Focus of the study

The present study focuses on analysing LCA studies whose goal is to support the selection of a strategy

Table 2.1 Classification of the number of studies about management of used paper covered by the literature search

Methodology used for the study			Perspective of the study	
			Company perspective (e.g. production process optimisation)	Society perspective (e.g. incineration versus recycling)
Comparisons based on physical units	Life cycle assessments	Case studies	17	20
		Methodological studies	3	7
	Other life cycle-based studies		1	5
Comparisons based on monetary units	Cost–benefit analyses	Case studies	2	10
		Methodological studies	—	5
	Other life cycle-based studies (e.g. life cycle costs)		—	7

Note: The total number of studies is 77. The shadowed cells indicate the studiy's subject of detailed analysis.

for the management of used paper. Most of the studies of this kind adopt a society perspective, and typically consist of a number of alternative scenarios that encompass more or less completely the options available in a given geographical area for the management of used paper. These options are mainly three: incineration (with or without energy recovery), landfilling and paper recycling. These studies are marked with shadow in Table 2.1.

Within this category of LCA studies, two sub-categories are distinguished.

- Case studies that use LCA as a tool for assessment of paper systems in a given geographical area, in other words, for the selection of different alternatives for recycling/disposal. These studies are made for supporting, for example, decision-makers in local, regional or national governments.
- Methodological studies that discuss the appropriateness of LCA as a tool for assessment of paper systems. These studies address LCA experts, and discuss LCA issues such as key assumptions and pitfalls to be aware of when carrying out an LCA in order to make the disposal/recycling scenarios fully comparable. The main objective of such studies is to discuss the LCA methodology and contribute to increase the reliability of such studies.

Some studies covering complete LCAs on other related waste streams (e.g. packaging waste, refuse derived fuel, municipal solid waste) have also been collected in order to be able to identify possible synergies. The results of these studies are not the subject of a detailed discussion.

The literature search has also covered a number of studies using monetary units (see Table 2.1). These studies are not analysed in detail, but their usefulness for supporting policy-making in the field of recycling, and their role as compared with LCAs is discussed in the final conclusions and outlook.

3 Framework for the assessment of the LCA studies

This section describes:

(1) the criteria used to select the LCA studies;
(2) the criteria used to evaluate the quality of the selected studies in relation to the goal of the project.

3.1 Selection of the LCA studies

The selection of the LCA studies has required the definition of a set of selection criteria. The criteria used in the present study are of three types:

3.1.1 LCA quality and LCA methodological criteria;
3.1.2 methodological criteria that are specific for paper/cardboard LCA studies;
3.1.3 other additional criteria.

The three used criteria are described in more detail in the following sections.

3.1.1. LCA quality and LCA methodological criteria

LCA is one of the most widely used and internationally accepted methods for analysing the environmental profile of products and systems. An LCA is a calculation of the environmental burden of a material, product or service during its lifetime.

The main goal of the present study is to analyse in detail a series of LCA studies, evaluate their conclusions and deduct if it is possible to make a generalisation of these conclusions. According to some references (e.g. Ekvall, 1996), not all LCAs analysing the management of waste paper have arrived at the same conclusions, and there are many methodological problems involved in carrying out such a study.

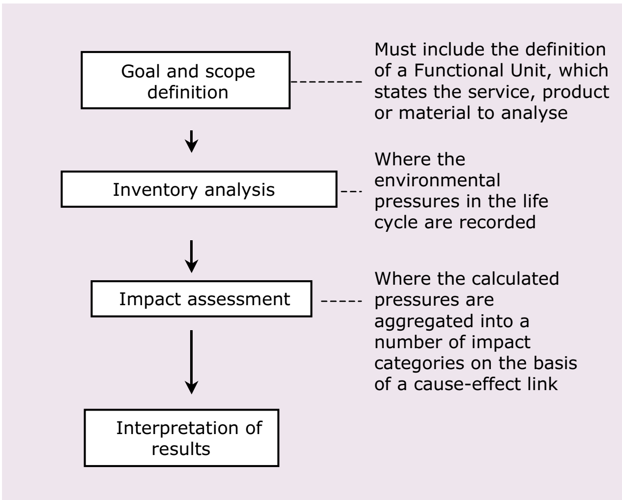
When the results from different comparative LCAs are analysed, it is important that an equivalent methodology has been applied in all the studies. In order to compare the results of the selected studies, one must examine if there are any differences in the LCA method used, what these differences are, and how they affect the results. Therefore, it is convenient that the LCA studies analysed fulfil certain criteria that make them comparable, and if possible follow a standard.

Several LCA guidelines exist that indicate how to carry out and ensure the quality of an LCA study, both at national and international level. One of them is the ISO 14040 series (European Committee for Standardisation, 1997), which is being use as reference in the present study.

Within the requirements of the ISO 14040 standards, the following criteria have to be observed.

- A life cycle assessment shall include the phases of goal and scope definition, inventory analysis, impact assessment, and interpretation of results (Figure 3.1).

Figure 3.1 Illustration of the phases of an LCA



- Comparative LCA studies disclosed to the public shall include the step of 'impact assessment'. An additional requirement is that the choice of environmental categories is as complete as possible as well as appropriate in relation to the goal of the study, so that comparison is fair and equivalent for the product alternatives.
- Systems shall be compared using the same functional unit and equivalent methodological considerations such as performance, system boundaries, data quality, allocation procedures, decision rules and impact assessment. Any

difference between systems regarding these issues shall be identified and reported.
- Besides ensuring accordance with the explicit requirements of the standard, the ISO standards require the critical review to ensure that the methods used to carry out the life cycle assessment are scientifically and technically valid. For the inventory phase, the most important issue in this context is the way data are aggregated. The scientific justification for aggregating data should be thoroughly reviewed. Also, the validity of the methods used for calculations should be reviewed.

As far as possible, the studies to be selected should fulfil the requirements indicated in the ISO 14040 series, but some studies elaborated before the publication of the standard have also been selected, after having checked that the main principles later required by the standard are followed.

3.1.2 *Specific methodological criteria for comparative paper/cardboard LCA studies*

Comparative LCA studies such as the ones analysed in this study are characterised by including a series of assumptions, which are not necessary in other non-comparative LCA studies. These assumptions are needed to ensure that the two or more systems to be compared are actually fully comparable, which in LCA terminology is formulated as 'systems which deliver exactly the same service(s)'.

The life cycle of paper in particular is characterised by a number of secondary services, including the following.

- *Generation of energy*. Wood fibres have a positive heating value, which in scenarios including incineration can be transformed into heat and power. This energy, which is a product provided by the scenarios including incineration, has to be provided as well by any scenario where the paper fibres are not incinerated but recycled or landfilled.
- *Forestry services*. Residues from forest thinning and pulp production such as bark and wood chips can also be used for heat and power production. Otherwise, they are left in the forest and can result in emissions of carbon dioxide and methane. Any energy obtained from forest residues has to be compensated for in the scenarios where wood extraction is not present. Similarly, if the two systems to be compared have different demands of virgin pulp, the forest land required for both systems will not be the same. The land not used for cultivation of paper forest is released for other uses and services, e.g. biomass fuel cultivation or recreational. These secondary services should also be compensated for.
- *Waste management systems*. A system with recycling does not have the same demand of disposal capacity (landfill/incineration) than a one-use system. The use or release of the landfill and/or incineration capacity that is different in the two systems compared should be compensated for.
- *Agronomic value*. If in one of the system's pulp sludge is composted and used as fertiliser, then an equivalent supply of the same service has to be provided in the system which is compared and has no pulp sludge.

A more detailed description of the mentioned secondary services is given in Section 3.3 below. A schematic illustration of the life cycle of paper, containing the abovementioned secondary services, is given in Figure 3.2. A technical description of the processing of used paper is given in Annex 3.

The life cycle of paper has additional characteristics which are important for an LCA. Paper, like glass, aluminium and steel, is a material that can be recycled. The LCA studies on such materials are characterised by the need to define clearly and explain transparently the material's anticipated loss of quality or 'grade' in the system where the material is recycled. The material grade loss implies the ratio at which recycled and recovered material can displace virgin material. While for aluminium, for example, this may well be around 1:1, it is not better than 1:0.8 for any paper or cardboard category.

The assumptions here explained have to be stated clearly in any LCA on paper in order to have two fully comparable systems. In most cases, it is not possible to make these assumptions objectively, and some kind of judgement or estimation has to be made on the basis of the available information. Such estimations cannot be said to be true or false, but they can be more or less justifiable and documented.

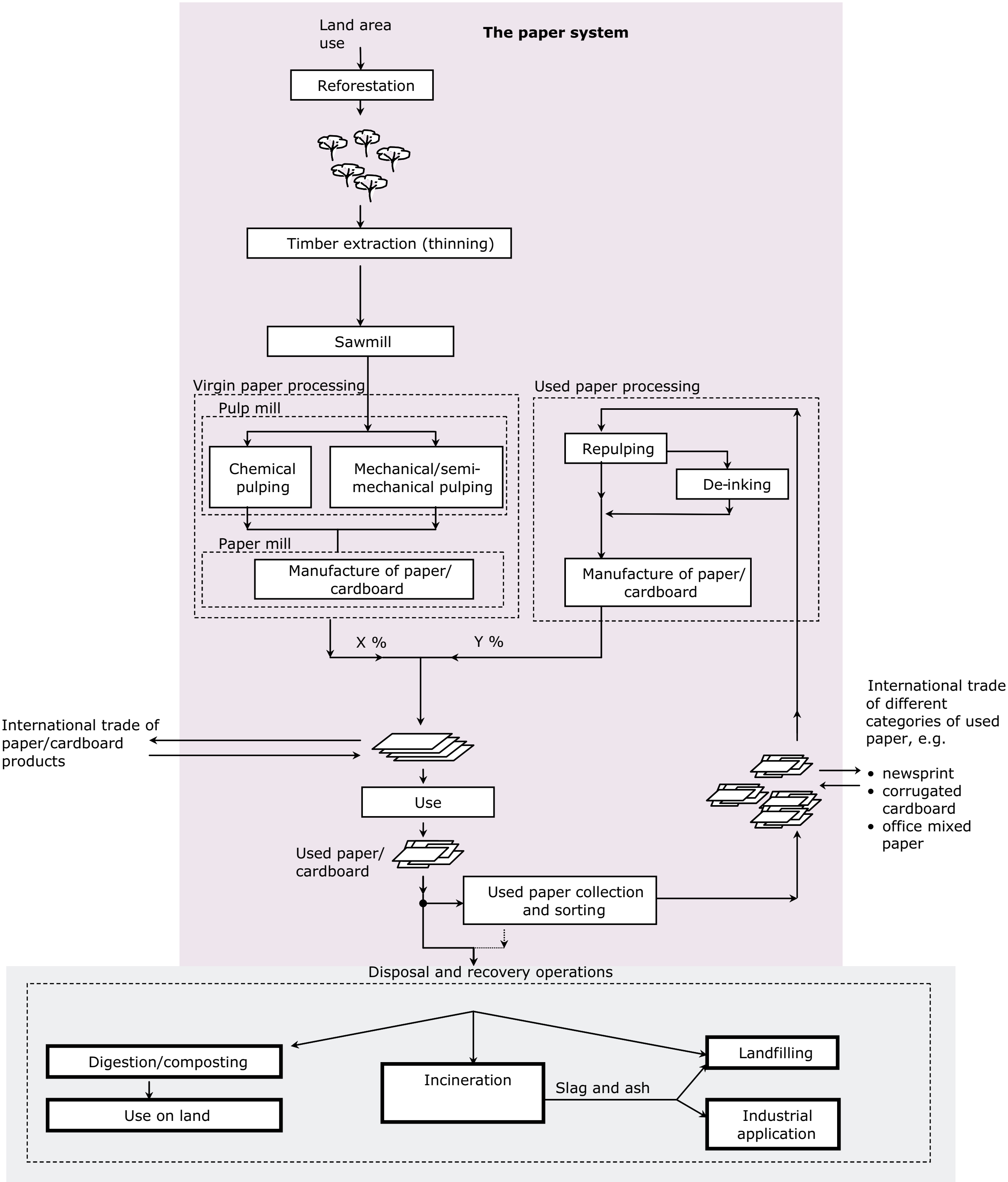
3.1.3 *Other selection criteria*

Other criteria that have been used to select the most relevant LCA studies are the following.

Perspective adopted

The selected LCA studies shall, to the extent possible, cover the comparison of different waste management options or scenarios. Some of the studies compare recycling with landfilling and others compare

Figure 3.2 Schematic diagram of the paper system, from production of virgin pulp to final disposal/recovery



recycling with energy recovery via incineration. The LCA studies with no comparison between scenarios are not interesting for the present study. The reason for this, as explained in Section 2.1, is that the assumptions, requirements and values made in comparative LCA studies fit best the goal of the present study, which is to supply information for the development of the thematic strategy on recycling.

Time frame

The time span of the decisions supported by the LCA is not necessarily the same from a company perspective than from a society perspective, because these studies have different goals and are designed to support different decisions. Within studies adopting a society perspective, the time frame can also be very different.

It should be kept in mind what the decision to be supported by a study is, since such a decision influences how the boundaries are defined and what the time perspective to be chosen is. Short-time decisions, 5–10 years, use different assumptions in the long-term strategic planning of 10–20 years and beyond, regarding, for instance, the relevant technology (average versus BAT), the data quality, the sources of energy, the environmental policies, the influence of the paper life cycle on other areas, the horizon of the emissions (e.g. 20 years versus 100 years), or the weighting factors chosen for the impact categories. Two basic time perspectives can, thus, be distinguished.

- Short-term. Boundary conditions are set by existing capital equipment and no new large investments are envisioned. This implies a fixed paper production capacity, and it may imply, for example, that incineration of used paper takes place at the expense of incineration of other wastes. Today's marginal energy technologies and fuel marginals are used in the modelling.
- Long-term. Capital investments may take place meaning that boundary conditions are not set by the capacity of existing equipment. New boundary conditions for energy systems and new fuel marginals may prevail, and scenarios should be made for possible futures.

Studies from most recent years are preferred

As mentioned in Section 2.1, most paper LCA studies were carried out in the period from 1995 to 2000. In addition, it was not until the mid-1990s that the first methodological articles describing key issues in paper LCAs were published (e.g. Ekvall, 1992, 1996). The results of the studies published before 1995 are most likely not to have considered key methodological questions involved in paper LCA, and therefore their results are to be taken with caution.

The type of paper and cardboard is not used as exclusion criterion

The first screening of some of the LCA studies that include analysis of different types of paper and cardboard indicate that the differences in the impacts from the life cycle of paper products are mostly not related to differences in the product, paper versus cardboard, but are rather related to assumptions of the system boundaries and technology choices (see, for example, Frees *et al.*, 2004; Environmental Defence, 2002). Therefore, LCA studies have not been excluded from consideration because of differences in the type of paper analysed.

An overview of the existing standard grades of recovered paper and board is given, for instance, in the 'European list of standard grades of recovered paper and board', published by the Confederation of European Paper Industries and the European Recovered Association, and available online at: http://www.erpa.info/Standard_Grades.htm.

3.2 Selected studies

As mentioned in Section 2.1, the literature search has revealed the existence of two kinds of studies of interest for the present project:

(1) methodology studies on LCA as a tool for decision-making in the management of used paper/cardboard;

(2) LCA case studies, primarily comparative LCAs including different management options.

From category 1, the following methodology studies have been used.

- Ekvall, T. (1992). *Life cycle analyses of corrugated cardboard: A comparative analysis of two existing studies*. CIT Ekologik report 1992:3. p. 56, Chalmers Industriteknik, Gothenburg, Sweden.
- Ekvall, T. (1996). *Key issues in the assessment of wood fibre flows*. 1996:1, Nordpap/DP2/20. CIT Ekologik, Chalmers Industriteknik, Gothenburg, Sweden.
- Ekvall, T. (1999a). Key methodological issues for life cycle inventory analysis of paper recycling. *Journal of Cleaner Production*, 7(4): pp. 281–294. Technical Environmental Planning, Chalmers University of Technology, Gothenburg, Sweden.
- Strömberg, L., Haglind, I., Jacobsson, B., Ekvall, T., Eriksson, E., Kärnä, A.. and Pajula, T. (1997). *Guidelines on life cycle inventory analysis of pulp and paper*. NordPap DP 2/30. Scanforsk — rapport 669. Nordisk Industrifond, Oslo, Norway.

From category 2, the following nine LCA studies, containing in total 73 scenarios, have been analysed in detail:

S1 — Tillman ***et al.*** **(1991) (four scenarios)**
Tillman, A. M., Baumann, H., Eriksson, E., Rydberg, T. (1991). Life cycle analyses of selected packaging materials. Quantification and environmental loadings. Offprint from *Miljön och förpackningarna*, SOU, 1991:76

S2 — Dalager ***et al.*** **(1995a–95d) (18 scenarios)**
Dalager ***et al.*** (1995a–95d). *Miljøøkonomi for papir- oq papkredsløb* (Environmental economics of paper and cardboard circulation. Part 1: Method description, material flow, and references). Working reports from the Danish Environmental Protection Agency, No 28–31 (in Danish): http://www.mst.dk/udgiv/Publikationer/1995/87-7810-353-3/pdf/87-7810-353-3.pdf.

S3 — Virtanen and Nilsson (1993) (one scenario)
Virtanen, Y., Nilsson, S. (1993). *The environmental impacts of waste paper recycling*. IIASA, Laxembourg (Austria).

S4 — Kärnä ***et al.*** **(1994) (two scenarios)**
Kärnä, A., Engström, J., Kutinlahti, T. and Pajula, T. (1994). 'Life cycle analysis of newsprint: European scenarios'. *Paperi ja Puu — Paper and Timber*, 76(4): pp. 232–237.

S5 — Ecobalance UK (1998) (one scenario)
Ecobalance UK (1998). *Newsprint — A life-cycle study.* An independent assessment of the environmental benefits of recycling at Aylesford Newsprint compared to incineration. Aylesford Newsprint Ltd, Aylesford, United Kingdom: http://www.aylesford-newsprint.co.uk/pdf/lcs.pdf

S6 — Grant et al. (2001) (four scenarios)
Grant, T., James, K., Lundie, S., and Sonneveld, K. (2001). *Stage 2 report for life cycle assessment for paper and packaging waste management scenarios in Victoria*. Melbourne, EcoRecycle Victoria. Australia: http://www.ecorecycle.vic.gov.au/asset/1/upload/Stage_2_Report_for_Life_Cycle_Assess_for_Packaging_Waste_Mg.pdf

S7 — Tiedemann ***et al.*** **(2001) (six scenarios)**
Tiedemann, A., Klöpffer, W., Grahl, B., and Hamm, U. (2001). *Life cycle assessments for graphic papers*. No 2/2001, Umweltbundesamt, the German Federal Environmental Agency, Berlin, Germany: http://www.umweltbundesamt.de/uba-info-medien-e/mysql-media-detail.php3?Kennummer=1925.

S8 — Environmental Defence (2002) (10 scenarios)
Environmental Defence (2002). *Life cycle environmental comparison — Virgin paper and recycled paper-based systems*. Paper task force, White Paper No 3. Environmental Defence, New York, USA: http://www.environmentaldefense.org/documents/1618_WP3.pdf.

S9 — Frees ***et al.*** **(2004) (27 scenarios)**
Frees, N., Hansen, M. S., Ottosen, L. M., Tønning, K., Wenzel, H. (2004). *Opdatering af vidensgrundlaget for de miljømæssige forhold ved genanvendelse af papir og pap* (Update of the knowledge basis on the environmental impact of paper and cardboard recycling). Submitted for publication in February 2004 to the Danish Environmental Protection Agency within the series 'Environmental Report' (in Danish).

The rest of the LCA studies from the initial literature list did not fulfil one or more of the requirements needed for their inclusion in this study. The most frequent reasons for not including them were:

- not comparative LCAs, no comparison between recycling and an alternative;
- only the abstracts are available, whereas the main, full-size reports including the background information are for one or other reason not of public access;
- not following the ISO standards or an equivalent LCA methodology guideline.

Some of the main features of the nine analysed studies are presented in Table 3.1. The last columns of Table 3.1 indicate whether the studies conclude that recycling is environmentally better than incineration or the opposite. All studies comparing recycling with landfilling of used paper conclude that recycling is the most favourable option of these two. Therefore, these results have not been included in Table 3.1.

All studies analysed include scenarios that compare recycling with another waste management option, be it disposal (e.g. landfilling, incineration without energy recovery) or recovery (e.g. incineration with energy use) ([1]). The number of scenarios has

(1) Disposal and recovery operations as defined in Annex IIB of the waste framework directive (75/442/EEC, as amended).

been simplified in some studies in order to fit to an actual comparison between recycling and either incineration or landfilling. This means that, for example, a comparison between three options such as (a) current ratio of paper recycling and incineration of residuals, (b) full incineration, and (c) a scenario with increased recycling do not represent three different comparison scenarios in the present study, but only one scenario where increased recycling is compared with full incineration.

It is important to observe that Study S9 (Frees *et al.*, 2004) is very complete and contains 27 scenarios

Table 3.1 Main features of the nine LCA studies analysed

					Number of scenarios				Main conclusions recycling versus incineration (²)				
	Name, year	Country of origin	Geographical scope	ISO 14040 or equi-valent?	Recycling versus landfilling Total: 19 (22)	Recycling versus incineration Total: 51	Perspective adopted (company/society)	Key methodological issues included?	Mostly favourable to incineration	Favourable to incineration under certain boundary conditions (e.g. paper type, % collection, incineration efficiency, geographical, population density, other)	No specific/definitve conclusions concerning comparison of treatment options	Favourable to recycling under certain boundary conditions(e.g. paper type, % collection, incineration efficiency, geographical, population density, other)	Mostly favourable to recycling
S1	Tillman *et al.* (1991)	Sweden	Sweden	No	2	2	Society	Few			X		
S2	Dalager *et al.* (1995a–95d)	Denmark	Denmark plus European imports	Yes	7	11	Society	Many				X	
S3	Virtanen and Nilsson (1993)	Austria	Europe	No	0	1	Society	Few			X		
S4	Kärnä *et al.* (1994)	Finland	Finland plus Germany	No	1	1	Society	Very few	X				
S5	Ecobalance UK (1998)	United Kingdom	United Kingdom plus worldwide imports	Yes	0	1	Company	Some					X
S6	Grant *et al.* (2001)	Australia	Australia plus worldwide imports	Yes	4	0	Society	Many	Compares only recycling to landfilling, and the conclusion is favourable to recycling				
S7	Tiedemann *et al.* (2001)	Germany	Germany plus worldwide imports	Yes	3 (¹)	3	Society	Many				X	
S8	Environmental Defence (2002)	USA	USA	No	5	5	Society	Many				X	
S9	Frees *et al.* (2004)	Denmark	Denmark plus European imports	Yes	0	27	Society	Most				X	

Note:

(¹) Combination of 30 % incineration and 70 % landfilling.

(²) All studies comparing recycling to landfilling of used paper conclude that recycling is the most favourable option of the two. Therefore, these results have not been included in Table 3.1.

for recycling versus incineration, which is more than half of the total scenarios for recycling versus incineration found in the literature (51 scenarios). It can be expected that the overall consideration of all scenarios will be heavily biased by the assumptions taken in this particular LCA. Therefore, the present study includes a separate assessment of the LCA studies **without** Study S9.

3.3 Criteria used for the analysis of the LCA studies

A number of key issues for the outcome of an LCA about paper disposal/recycling have been identified. These key issues have been identified using as background the following material:

- the methodology studies by Ekvall (1992, 1996 and 1999a) and Strömberg *et al.* (1997);
- the methodological explorations included in Frees *et al.* (2004) and Dalager *et al.* (1995);
- the general LCA theory.

The key issues are divided into four main categories:

- system boundary assumptions, including issues of system equivalence, identification of marginal process technologies, system delimitation, time perspective definition and geographical delimitation;
- impact assessment categories;
- data age and quality;
- the paper/cardboard/pulp category in question.

3.3.1 System boundary issues

A comparative LCA should, as far as possible, reflect the environmental consequences occurring when choosing one alternative over the other. This implies that all essential activities/processes in the technosphere affected by the choice should be included in the system.

The first and probably most important requirement deriving from this is that the compared systems should be equivalent with respect to the goods and services they provide to society. If, for example, alternative A lacks parts of the goods/services provided by alternative B, other processes/systems will automatically take over and supply these services, if A is chosen instead of B. Therefore, these other processes/systems and their environmental impact must be included to account for the resulting environmental consequence of choosing A over B. If, for example, alternative A implies a supply of energy to the grid besides the supply of paper, alternative B must be adjusted to include the same energy service supplied to society.

The second requirement of almost equal importance is that the processes/technologies included in the system should be the marginal ones, which means the ones responding to a change in demand of the products in question. If , for example, alternative A implies a change in demand of virgin paper, the processes in the virgin paper system responding to the change in demand should be included and only these. A virgin paper

Table 3.2 Key system boundary issues in the LCA of paper and cardboard

Raw materials/forestry	1	Alternative use of land/wood included?
	2	Saved wood used for energy?
	3	Wood marginal
Paper production	Virgin paper	
	4	• Electricity marginal
	5	• Steam marginal
	Recovered paper	
	6	• Electricity marginal
	7	• Steam marginal
	8	Energy export from virgin paper included?
Disposal/energy recovery	9	Which is the main alternative to recycling: incineration or landfilling?
	10	Emissions from landfill included?
	11	Energy from incineration substitutes heat?
	12	Energy from incineration substitutes electricity?
	13	Alternative use of incineration capacity included?
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?
	15	Handling of rejects and de-inking waste from paper recovery included?

Note: The issues are numbered for comparison with Figure 3.3.

production taking place in Norway does, for example, draw its electricity from the Norwegian grid, and Norwegian electricity is over 99 % produced from hydropower. A change in demand for electricity in Norway will, however, not cause a change in the production of hydropower in Norway, because this electricity is of economic priority and of limited availability. Instead, a change in electricity demand in Norway will cause a change in import or export of electricity to neighbouring countries and cause a change in electricity production there. Thus, the resulting change in electricity production, which is called the electricity marginal, should be identified and included.

Which processes are in fact the marginal ones depends on the geographical scope and the time perspective, as they change from place to place and over time. Geographical scope and time perspective are, thus, not independent criteria, but part of the issue of identifying the right marginals.

The overview of the identified essential system boundary criteria, divided on the stages of the life cycle of the paper, is presented in Table 3.2 and described in detail below.

The location of the 15 issues in the paper system is illustrated in Figure 3.3.

System boundary issues in the raw material/ forestry stage

When more paper is recycled, in most cases raw material for virgin paper production will be saved. This releases wood and/or forest area for other uses. Whether this should be accounted for or not depends on the scarcity/availability of forest area/ wood/biomass and may thus depend on the time perspective if changes over time can be expected. In some of the analysed LCAs, scenarios are included modelling the use of saved wood for energy purposes. This key issue is indicated in positions 1 and 2 in Figure 3.3.

If wood is not a priority resource, it is taken in some studies as the marginal energy source. In the case that wood is or is expected to be of economic priority and limited availability in the studied time frame (like hydropower today), wood will not be the marginal resource either as raw material or as fuel. In this case, the use of wood will take place at the expense of its marginal, for example, fossil fuels. This key issue is illustrated in position 3 in Figure 3.3.

System boundary issues in the production stage

In the production of virgin paper, the majority of energy supply derives from wood, and in Scandinavian countries, in many cases, from hydropower. The identification of the true marginal for these energy supplies is considered of utmost importance in most methodological references consulted (e.g. Ekvall, 1996). These key issues are indicated in positions 4 and 5 in Figure 3.3. Moreover, some virgin paper/cardboard production, especially corrugated cardboard production, gives rise to excess energy via incineration that is exported to the public power grid. This should be accounted for properly (see position 8 in Figure 3.3).

In most cases, energy for paper recovery derives from fossil fuels, but it may also derive from biomass, and moreover, some companies have established their own heat and power co-generation plant. It is important to identify the true marginals for steam and electricity in such cases. This key issue is indicated in positions 6 and 7 in Figure 3.3.

In addition, paper recovery gives rise to rejects and de-inking wastes, the handling of which may give rise to both environmental impacts and/or secondary services that should be accounted for. This key issue is illustrated in position 15.

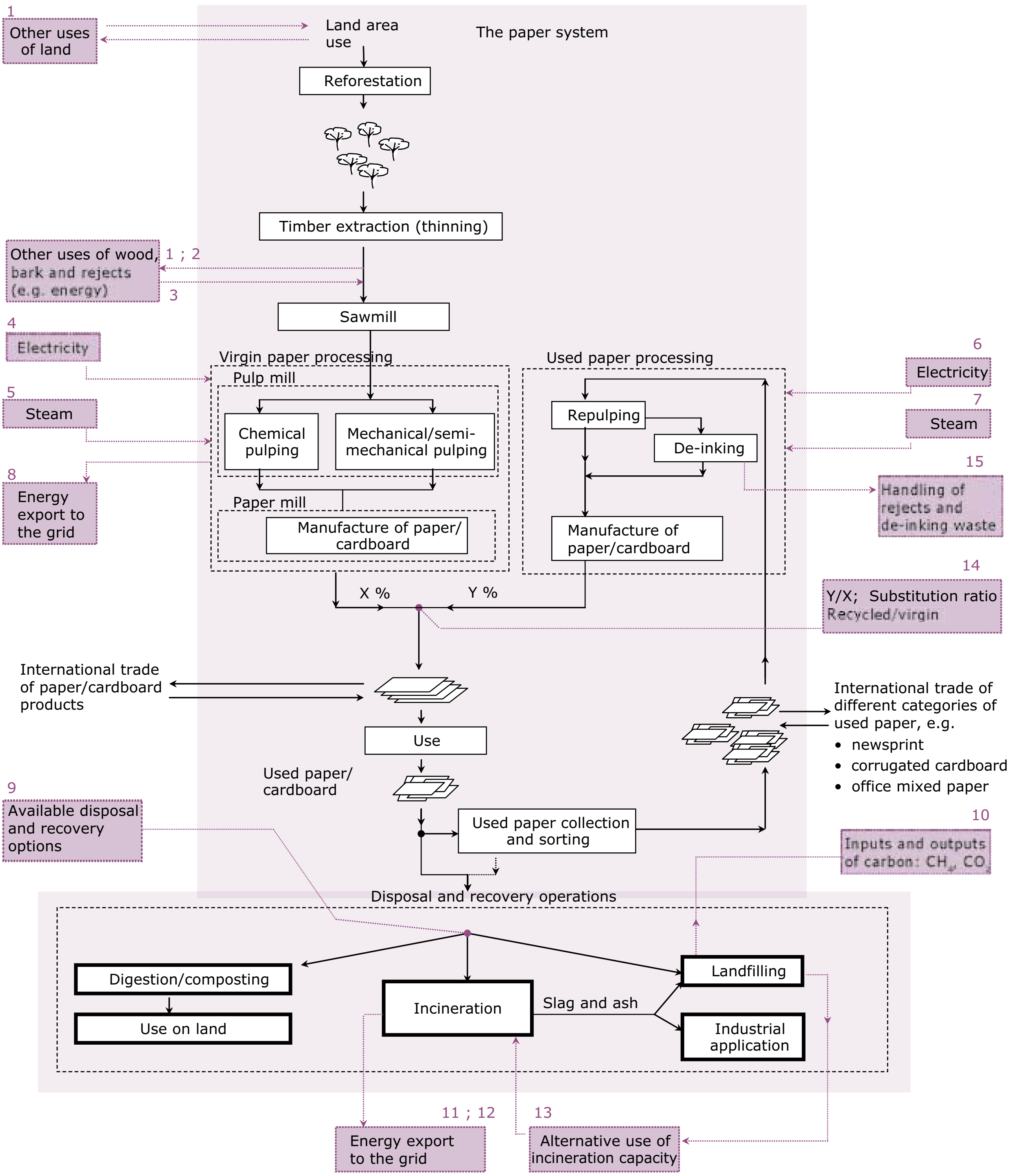
System boundary issues in the disposal/energy recovery stage

The anticipated disposal route or combination of disposal routes is important. But especially, it is important to clarify the increases and decreases in disposal routes when changes in the system occur. If, for example, an increase or decrease in recycling is studied, it should be clear if such an increase/ decrease is done at the expense of incineration, landfill or other disposal/recovery route, or a mix of these. This key issue is depicted in position 9 in Figure 3.3.

Emissions from landfills tend to have a high significance in the overall contribution to global warming, due to the formation and release of methane. However, such emissions are not always accounted for in all LCAs. The release of methane in other disposal routes (composting, incineration) is normally not so important. This key issue is indicated in position 10 in Figure 3.3.

Paper and cardboard have a relatively high heating value, similar to wood, and this energy can be released and utilised via incineration. In many incineration plants, this energy can be transformed into electricity and supplied to the grid, or supplied directly as heat via, for example, district heating. In LCAs, this recovery is considered to a varying degree and is divided differently between electricity and heat. Moreover, electricity and heat from incineration plants substitute

Figure 3.3 The paper system



Note: The shaded boxes indicate the parts of the paper system which are important to define clearly and justify in a comparative LCA, in order to ensure that the systems defined are fully comparable.

electricity and district heating on the public grid to a varying degree depending on geographical location and time of the year. These issues are highly important to identify and get right. They are illustrated in positions 11 and 12 in Figure 3.3. When paper/cardboard recycling is done at the expense of incineration/landfilling, the capacity of these facilities will be released. In the short term, this may imply the use of, for example, the incineration capacity to take in more municipal solid waste that would otherwise have gone to landfills. This should be taken into account, as indicated in position 13 in Figure 3.3.

Finally, recovered paper and virgin paper do not have the same quality/functionality. This implies that a higher mass has to be used per functional unit, when the paper has a high content of recycled fibre than a low content. The reason is that fibres become shorter on recycling, and after a maximum of six or seven times of recycling, fibres eventually become too short for further recycling. The consequence is that new, longer fibres have to be added into the paper system to keep up the quality. Any recycling cycle gives rise to a need for a certain amount of virgin paper input, ranging normally from 20 % to almost 100 %. In the modelling of the recycling, therefore, it should be anticipated that recovered paper cannot substitute virgin paper at a 1:1 ratio, but less, like a 1:0.8 ratio, where the 20 % remaining is supplied with virgin fibres. This key issue is indicated in position 14 in Figure 3.3, not meaning that the physical flow of virgin fibres occurs at this exact point, but just representing that the overall ratio of recycled fibres to virgin fibres can be illustrated in this point of Figure 3.3.

3.3.2. Impact assessment categories

The energy consumption of paper systems is probably the most significant single source of environmental impact (see, for example, Ekvall, 1996; Virtanen and Nilsson, 1991; Frees *et al.*, 2004). All LCAs analysed include this category, and most of them also include specific accounts for the energy balance of the systems.

Table 3.3 Environmental impact categories used for the assessment of paper systems

Energy use/generation
Resource consumption
Energy-related impacts
Toxicity of emissions
Waste generation
Wastewater
Other, for example, land use, biodiversity

Due to the geographical differences in the fuel type used and in the energy marginals from place to place and from time to time, it is also necessary to supplement the energy accounting by a translation into the energy-related environmental impacts. These impacts are essentially the global warming potential, the acidification potential, the nutrient enrichment potential and the photochemical ozone formation potential.

Generally, the production of virgin paper gives rise to higher and more polluted discharges of wastewater than recycling. Some LCA studies analysed make an account of wastewater discharge and wastewater toxicity while others do not. Before the 1980s and early 1990s, free chlorine was used to bleach the paper, but today the use of free chlorine has ceased and chlor-dioxide or other means of bleaching such as ozone have taken over in Europe (European Commission, 2001). The significance of including toxicity/wastewater discharge in Europe is, therefore, not as high as it was in the past. However, the issue is still relevant because large amounts of new and waste paper are imported/exported.

The use of land/forest area differs from virgin paper to recovered paper production, and this may have significance. In a comparative LCA, it can be dealt with by including alternative uses of the land/wood in the system or by including land use as an impact category. Few of the analysed studies include the use of land as an independent category.

Table 3.3 illustrates the impact categories for the environmental assessment of paper systems used in this study, representing the scope of inputs contained in the analysed LCAs.

Transportation

The importance of transportation in the overall environmental impact of the paper cycle is very small. Among the LCA studies analysed, Tillman *et al.* (1991) indicate that its contribution to the overall energy profile is less than 2 %. Frees *et al.* (2004) conclude that transportation in the paper system is approximately 0.4 % of the total energy use in the system. Most of the LCA studies analysed assume collection systems based on large containers distributed in household areas or special containers for paper from industrial producers and commercial activities.

The mentioned percentages can have exceptions in extreme cases such as scenarios with very high transportation requirements, for example, systems where paper is collected from the individual households instead of being collected in larger, centralised containers.

Transportation can contribute significantly to other specific emissions, for example, of CO, NO_X, or hydrocarbonic emissions, where its contribution can be up to 75 % of the total. However, the contribution of these emissions to the associated environmental impacts is in most cases less than 5 % (Tillman *et al.*, 1991).

3.3.3 Data age and quality

The age and quality of the data should, of course, be sufficient and representative for the consequences of choosing one alternative over the other. However, in the present study this has not been found to be a major concern, despite the difference of publication date between the studies (1991 to 2004).

3.3.4 Paper/pulp category

There are significant differences in some of the environmental impact categories between the various paper/pulp types. Virgin kraft pulp has a high total energy consumption, however most of it is produced internally with wood as fuel resource. Virgin thermo-mechanical pulp (TMP) and chemical-thermo-mechanical pulp (CTMP) have a much lower energy consumption, but this is mainly in the form of electricity. The marginal of this electricity is in most countries exclusively based on fossil fuels. When considerations of energy marginals come into the picture, these differences have large implications on the overall environmental consequences. It is therefore necessary and important to clarify what type of pulp or paper/cardboard is being studied in each scenario.

4 Results and discussion

4.1 Justification and transparency of the key assumptions in the LCA studies

In the LCA studies, the key assumptions are included at two levels.

(1) Are the key assumptions considered in the LCA? Is the inclusion/exclusion documented transparently?
(2) How are the key assumptions dealt with? Are the choices connected to the assumptions justified transparently?

Table 4.1 gives an overview of the extent to which the different studies have considered the 15 key system boundary issues described in Chapter 3.

Table 4.1 indicates whether the key issues have been considered and documented or if they are not considered (indicated as 'n.i.', no information, in Annex 4). It is observed that the assumptions are very differently represented in the studies. Some of the assumptions are included in most of the studies, for instance, the consideration of the type of energy used in the different processes and the generation of energy in incineration plants. Most studies include

Table 4.1 Overview of the extent to which the 15 key system boundary issues are included in the LCA studies analysed

Code	System boundary conditions		Number of studies	Studies that consider in any of the scenarios the given boundary condition (%)	Evaluation ☺ 😐 ☹
1	Alternative use of land/wood considered?	Considered	3	33	☹
		n.i.	6	67	
2	Saved wood used for energy considered?	Considered	3	33	☹
		n.i.	6	67	
3	Wood marginal considered?	Considered	3	33	☹
		n.i.	6	67	
4	Virgin paper — Electricity marginal considered?	Considered	9	100	☺
		n.i.	0	0	
5	— Steam marginal considered?	Considered	8	89	☺
		n.i.	1	11	
6	Recovered paper — Electricity marginal considered?	Considered	8	89	☺
		n.i.	1	11	
7	— Steam marginal considered?	Considered	6	67	☺
		n.i.	3	33	
8	Energy export from virgin paper considered?	Considered	3	33	☹
		n.i.	6	67	
10	Emissions from landfill considered?	Considered	7	78	☺
		n.i.	2	22	
11	Energy from incineration substitutes heat — considered?	Considered	5	56	😐
		n.i.	4	44	
12	Energy from incineration substitutes electricity — considered?	Considered	7	78	☺
		n.i.	2	22	
13	Alternative use of incineration capacity considered?	Considered	3	33	☹
		n.i.	6	67	
14	Data on the substitution ratio recycled/ virgin paper considered (1:1 or 1:0.8 or 1:0.5 or other)?	Considered	5	56	😐
		n.i.	4	44	
15	De-inking sludge considered?	Considered	6	67	☺
		n.i.	3	33	

Note: n.i.: no information.

also considerations to the emissions from landfills, although in different levels of detail.

Conversely, barely one third of the analysed LCA studies specify the assumptions made about the forestry secondary services, and also only one third include considerations of the flow of wastes if the incineration/landfilling capacity is modified.

Likewise, only half of the studies justify the substitution ratio recycled/virgin paper considered, and only half of the studies make any consideration to the use of heat energy in incineration plants.

The scenarios and not the studies are used as reference

The studies which have most scenarios are Dalager *et al.* (1995) (18 scenarios), Environmental Defence (2002) (10 scenarios) and Frees *et al.* (2004) (27 scenarios). Tiedemann (2001) includes also numerous scenarios, but a selection of six of these scenarios has been made based on their relevance for the present study. The LCA studies mentioned are among the most complete ones regarding the inclusion of the key assumptions. This relationship is somehow logical, since the sensitivity of the results of an LCA to a given key assumption is in many cases analysed by setting up an additional scenario which includes a variation of the key assumption. It is therefore natural to conclude that an analysis of the data by scenarios (74) and not by studies (9) covers more cases which include the 15 key assumptions. A distribution of the inclusion of the assumptions by scenarios and not by studies is presented in Annex 5, Table A5.5.

4.2 Distribution of the results of the reviewed LCAs

Figures 4.1 to 4.3 summarise the results from the LCAs analysed. All the details and the background data for these figures can be consulted in Annexes 4 and 5. The results are grouped into three categories:

(1) results from the 19 scenarios that compare recycling with landfilling (Figure 4.1).
(2) results from the 51 scenarios that compare recycling with incineration, including all studies (Figure 4.2).
(3) results from the 24 scenarios that compare recycling with incineration, where Study S9 and its 27 scenarios have been excluded (Figure 4.3).

Figures 4.1 to 4.3 present the percentage of scenarios, from the total of scenarios considered in a given figure (i.e. 19 scenarios for recycling versus landfilling, 51 scenarios for recycling versus incineration with Study S9 and 24 scenarios without Study S9), that are either favourable to recycling (marked 'recycling better than alternative') or favourable to the alternative. The alternative is respectively landfilling in Figure 4.1 and incineration in Figures 4.2 and 4.3.

The percentage of scenarios favourable to a certain management option for waste paper is presented in these figures as a function of the 15 key assumptions described in Chapter 3. This has allowed identifying three main characteristics in the figures.

(1) The distribution of the results of the analysed LCA studies, indicating whether recycling is environmentally preferable to incineration/landfilling. If the bars of a graph are on the right-hand side (from 0 to + 100 %) in a given environmental impact category (energy, toxicity, etc.), this indicates that most studies obtain results showing that recycling is more favourable than the given alternative, be it incineration or landfilling. Conversely, if the bars in a figure are mostly on the left-hand side (from – 100 % to 0), it indicates that in most LCA studies recycling is not the best option regarding the environmental impact category of the graph.

(2) The figures indicate, as well, the key assumptions the inclusion or exclusion of which are prone to have a significant influence on the results of an LCA study. If there is a large difference between the results obtained in scenarios with or without a given key assumption, this difference can be an indication that the inclusion of the key assumption influences the result obtained. Moreover, if the one choice on the assumption implies the results being, for example, 100 % in favour of recycling, whereas the other choice implies a less clear 'answer' as to the preference between recycling and incineration/landfilling, the assumption will also be a significant one. In this way, an identification of the most essential of the key assumptions can be made, classifying them into more and less determinant on the result of an LCA study.

    In addition, Figures 4.1 to 4.3 help to establish causal relationships between the results obtained by certain LCA studies and the assumptions taken. For instance, a study where the utilisation of the energy from incineration is not considered may tend to favour recycling. However, it must be taken into account that the presence of a scenario on the right- or left-hand side of the diagram is not necessarily connected to a given key assumption, but could be the result of the combination of choices made in the remaining 14 assumptions.

(3) The length of the bars or percentages in Figures 4.1 to 4.3 represent how well represented a given key assumption is. Long bars covering high percentages of the scenarios (e.g. in the energy categories) have a higher statistical value than short bars representing only one or two scenarios (e.g. toxicity categories). If an important key assumption has not been included in most LCA scenarios, the results presented in the figures may not be as reliable as if the key assumption is included and justified in all scenarios. The representation as percentages given has one minor disadvantage: it does not illustrate the results of the studies which are neither favourable nor contrary to recycling. However, these results represent in most cases less than 10 % of the studies and therefore do not contain substantial information useful for decision-making. These percentages explain why the sum of the percentages of the bars in Figures 4.1 to 4.3 does not add up to 100 % in all key assumptions. The numerical values of all results of the scenarios are presented in Table A5.4, Annex 5.

4.3 Recycling versus landfilling

Figure 4.1 illustrates that recycling is more favourable than landfilling in almost all the scenarios and all the environmental impact categories considered, except for toxicity and resource consumption. The results from the LCA studies reflect that the environmental benefit of recycling is especially clear in the categories 'energy use', 'energy-related impacts', 'waste generation' and 'wastewater'.

All the impact categories considered are reviewed in the following.

Energy use

This category is present and well documented in most of the scenarios. Regardless of the choice made in the key assumptions, more energy is used in virgin paper production and disposal via landfill than by recycling. This robustness is due to the fact that energy consumption is a function of the technology used for virgin and recycled paper processing, and to a minor extent to the system definition and boundary conditions of the paper system. Virgin paper production uses more energy because it requires harvesting of wood and a pulping process, followed by refining and drying. This 'embodied energy' is lost when paper is landfilled. Production of recycled paper uses recycled paper mass, which has already been refined, and only the energy for repulping, mixing and drying is needed.

Energy consumption data are, in general, easier to obtain than energy origin data and especially marginal energy data. Obtaining reliable data in other impact categories such as waste, resource consumption, and especially toxicity and land use can be more difficult.

Resource consumption

The resources category is highly influenced by the definitions of what type of resources are to be included. In some studies it is not specified whether resources such as wood and water are renewable (unlimited availability) or limited, and if they are included or not under this category, which helps to explain the differences observed in the results from the studies.

In the studies where wood and water are considered unlimited resources and are therefore not included, most of the consumption of resources are fossil fuels and the chemical additives for paper (e.g. sulphates, lime). The results from these studies indicate that the paper recycling system is just more environmentally favourable to the landfill system and certainly dependent on some of the 15 assumptions.

Energy-related impacts

The energy-related impacts are clearly favourable to recycling rather than landfilling. These impacts depend largely on the energy marginals (both electricity and heat) for the production of both virgin and recycled paper. If wood exists in unlimited amounts, and is used as fuel for virgin paper production, whereas fossil fuels are used for recycled paper production, then the overall picture can tend to be favourable to the system using (and landfilling) virgin paper in some but still the minority of cases (see Figure 4.1). If, on the other hand, a mix of wood, fossil fuels and other energy sources is used in both production systems, then paper recycling systems tend to be favoured because of an overall lower energy use.

Toxicity

The results from the toxicity category are characterised by a very low representativeness: in

Figure 4.1 Recycling versus landfilling

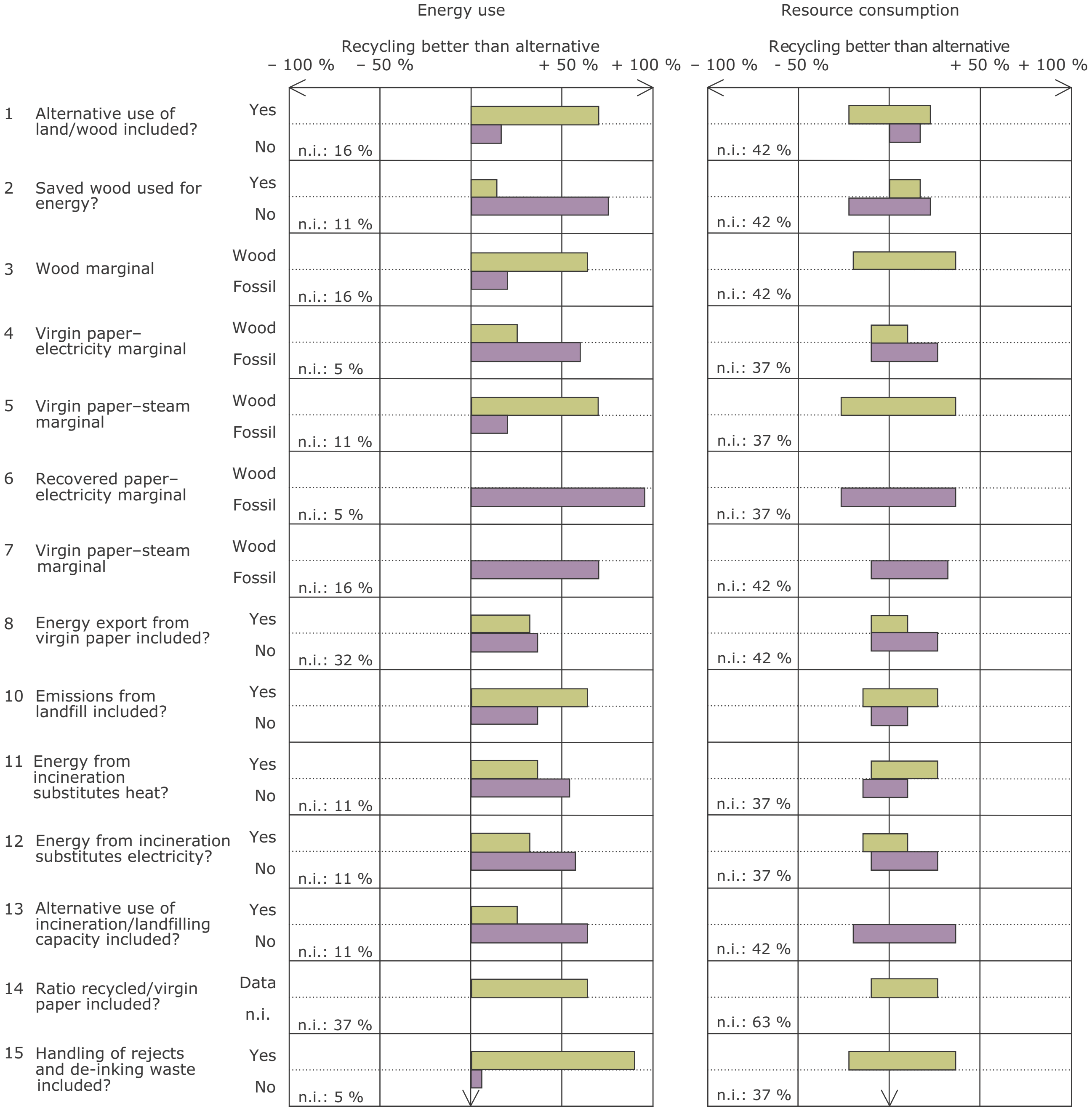


Figure 4.1 Recycling versus landfilling (continued)

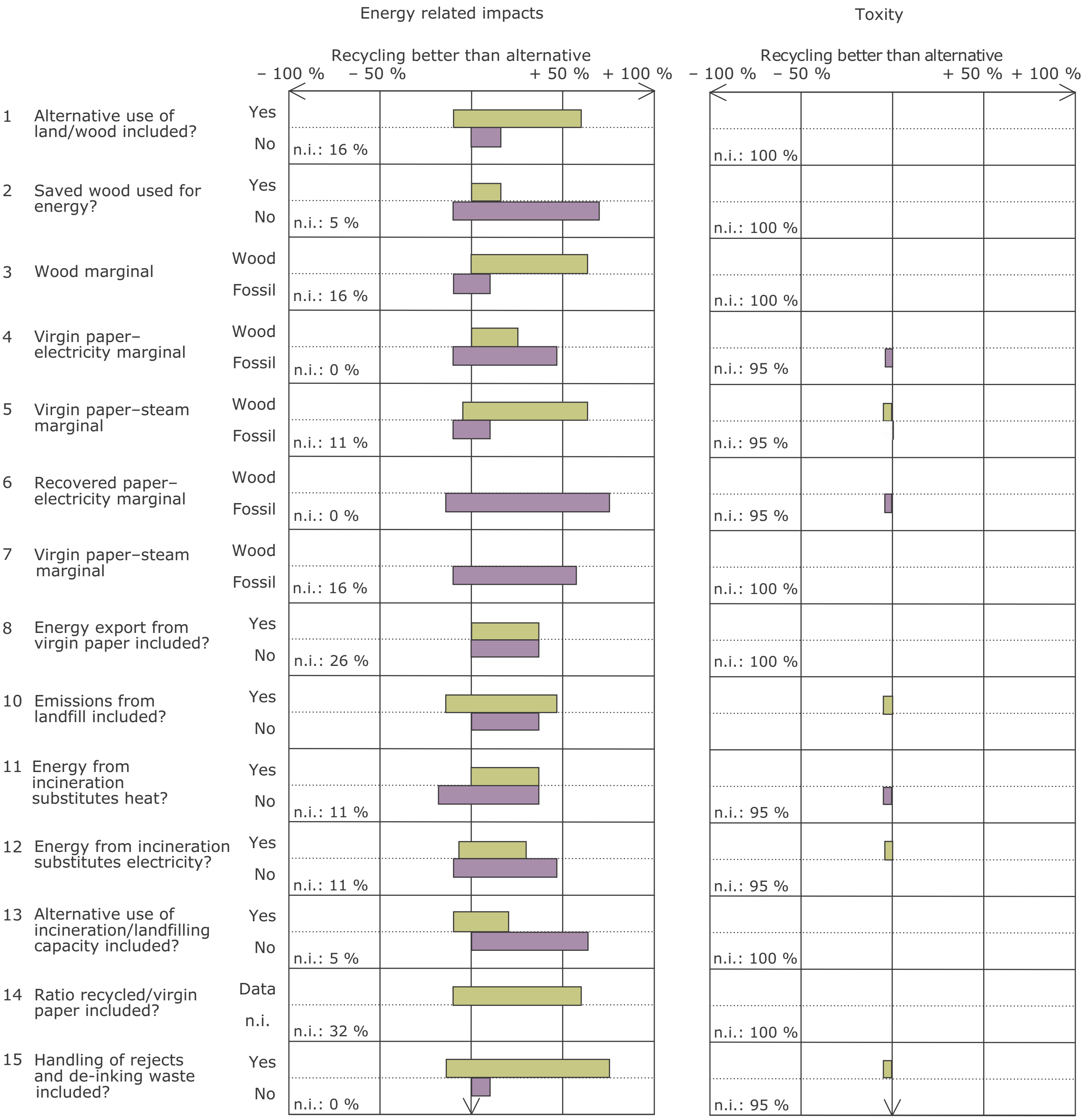


Figure 4.1 Recycling versus landfilling (continued)

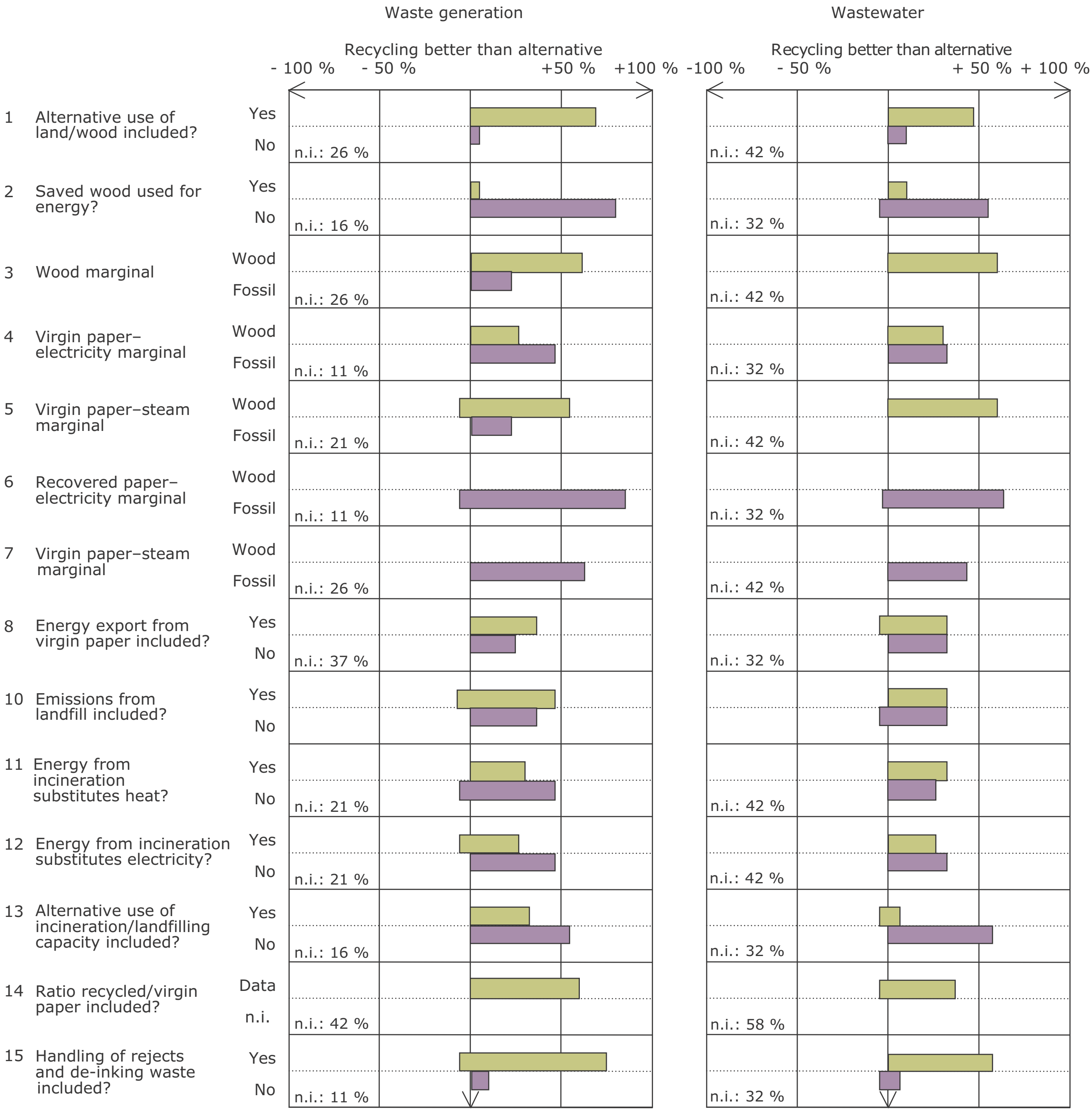


Figure 4.2 Recycling versus incineration, Study S9 included

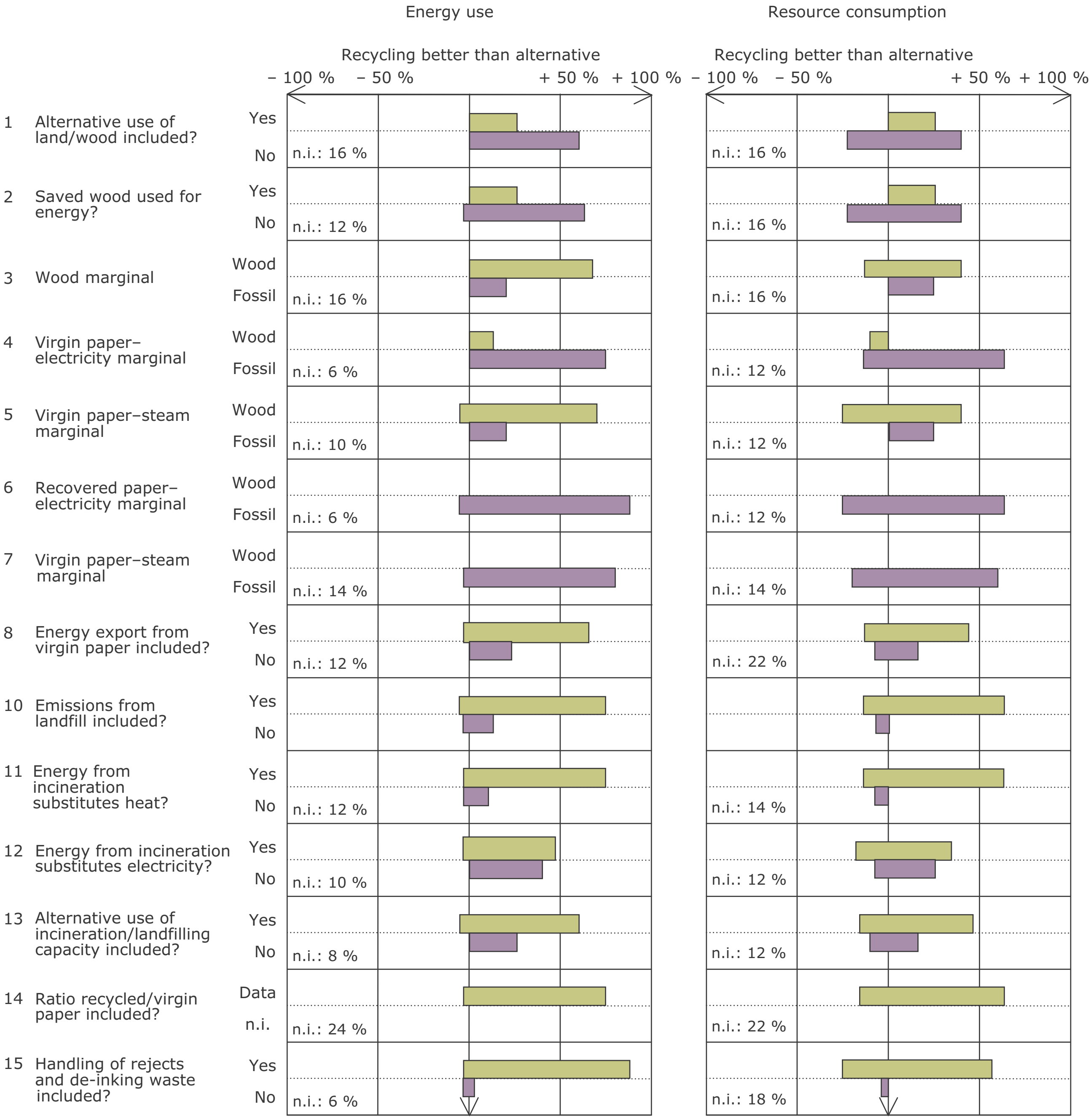


Figure 4.2 Recycling versus incineration, Study S9 included (continued)

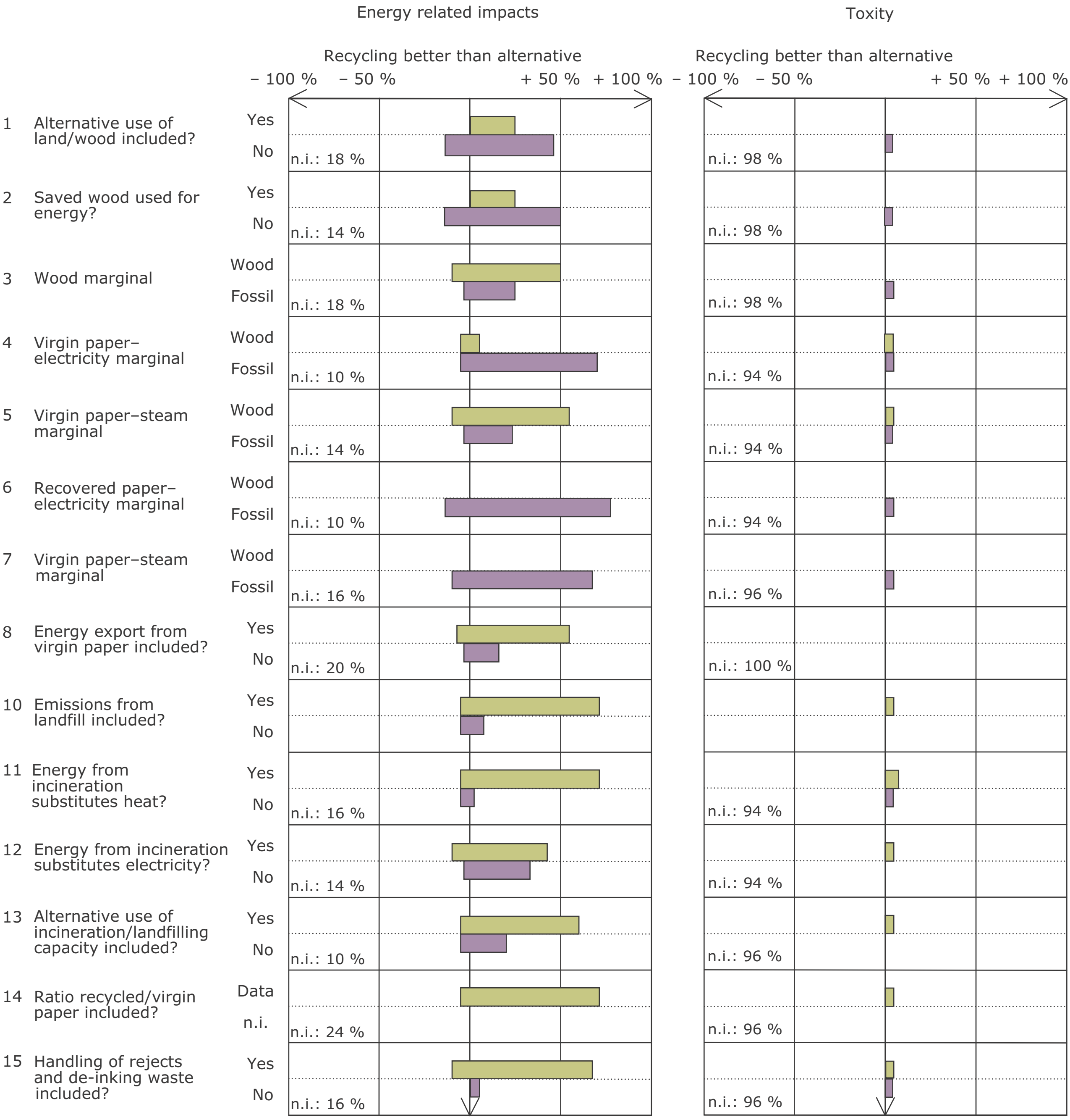


Figure 4.2 Recycling versus incineration, Study S9 included (continued)

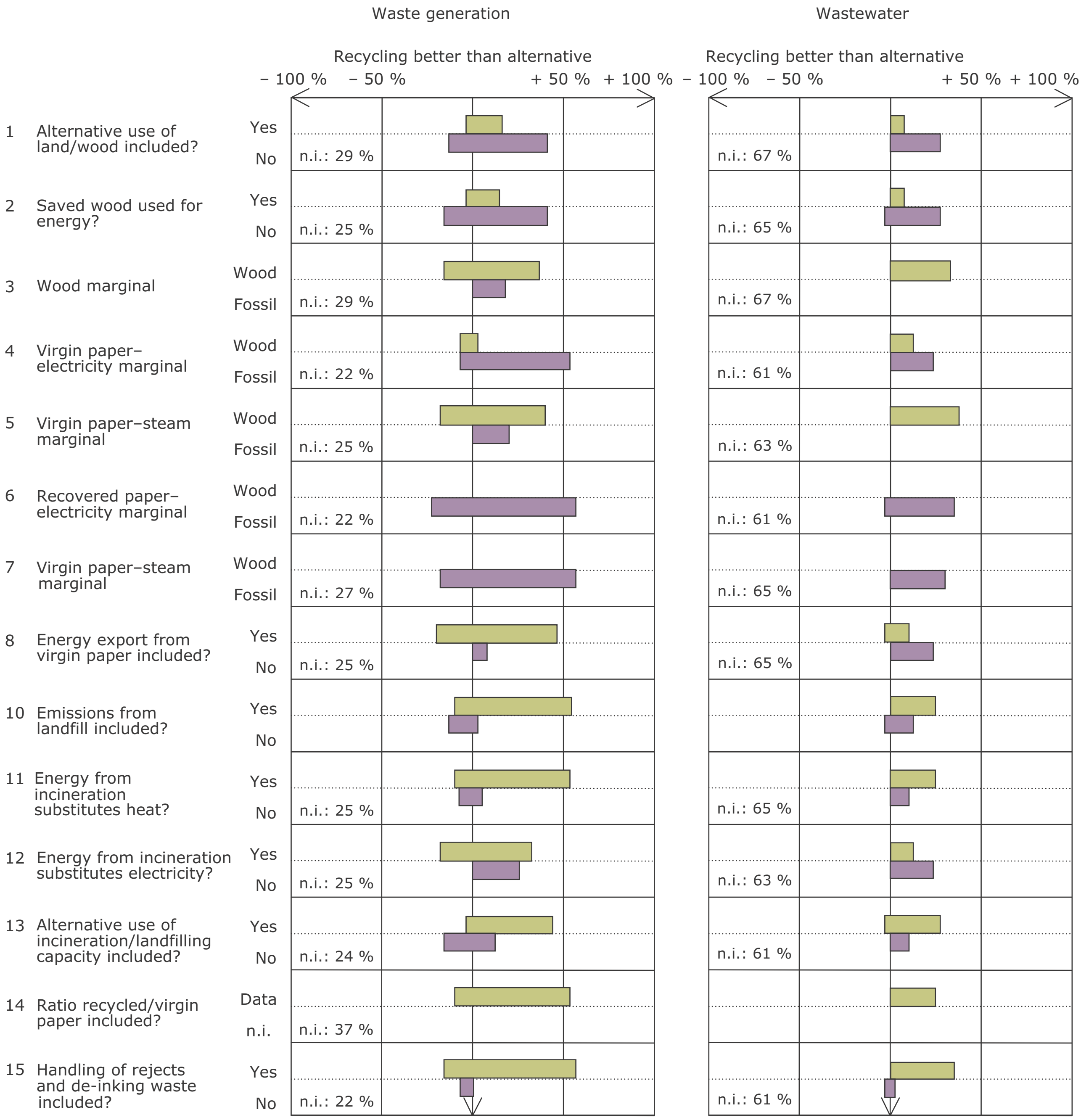


Figure 4.3 Recycling versus incineration, without Study S9

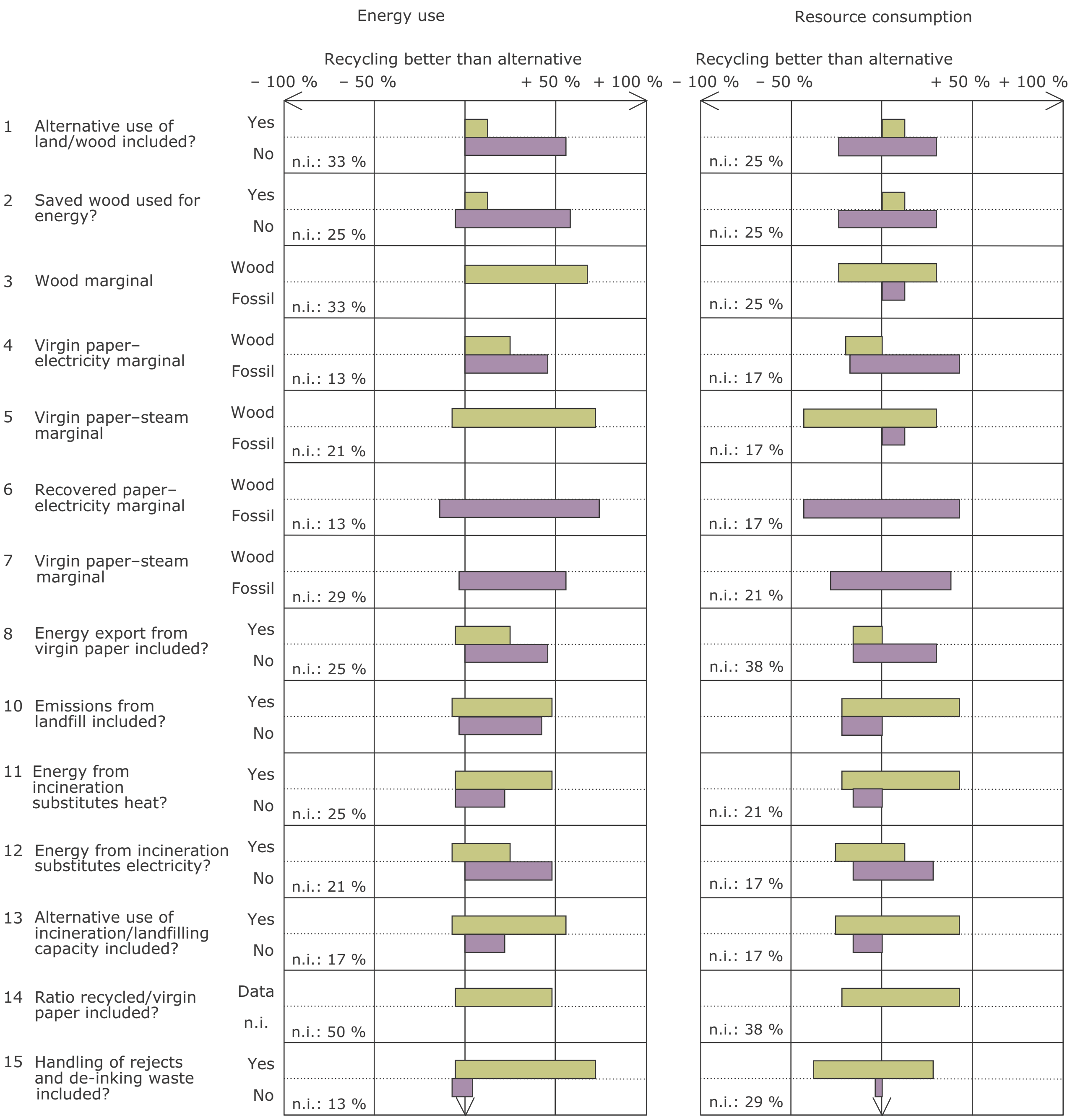


Figure 4.3 Recycling versus incineration, without Study S9 (continued)

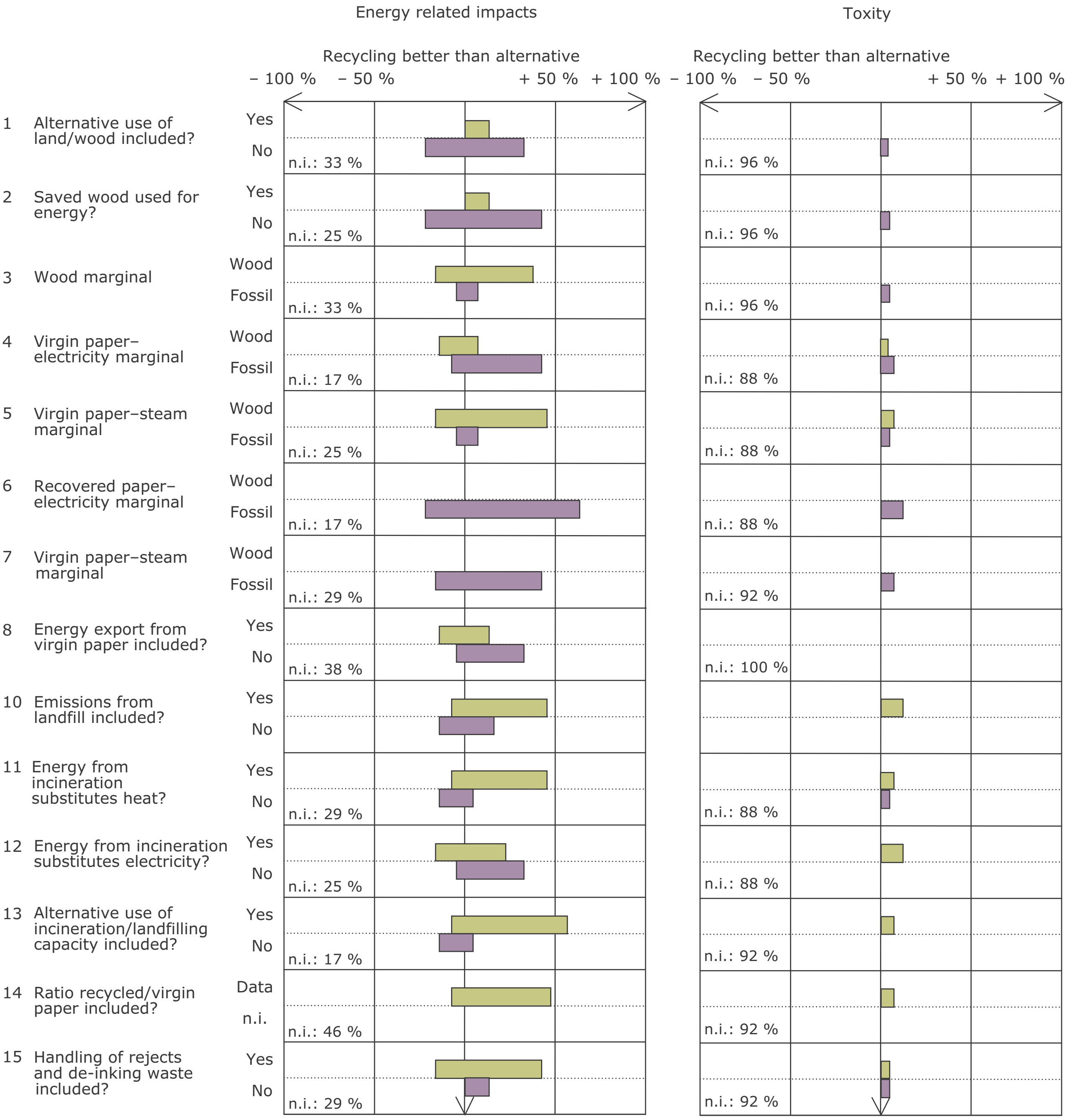
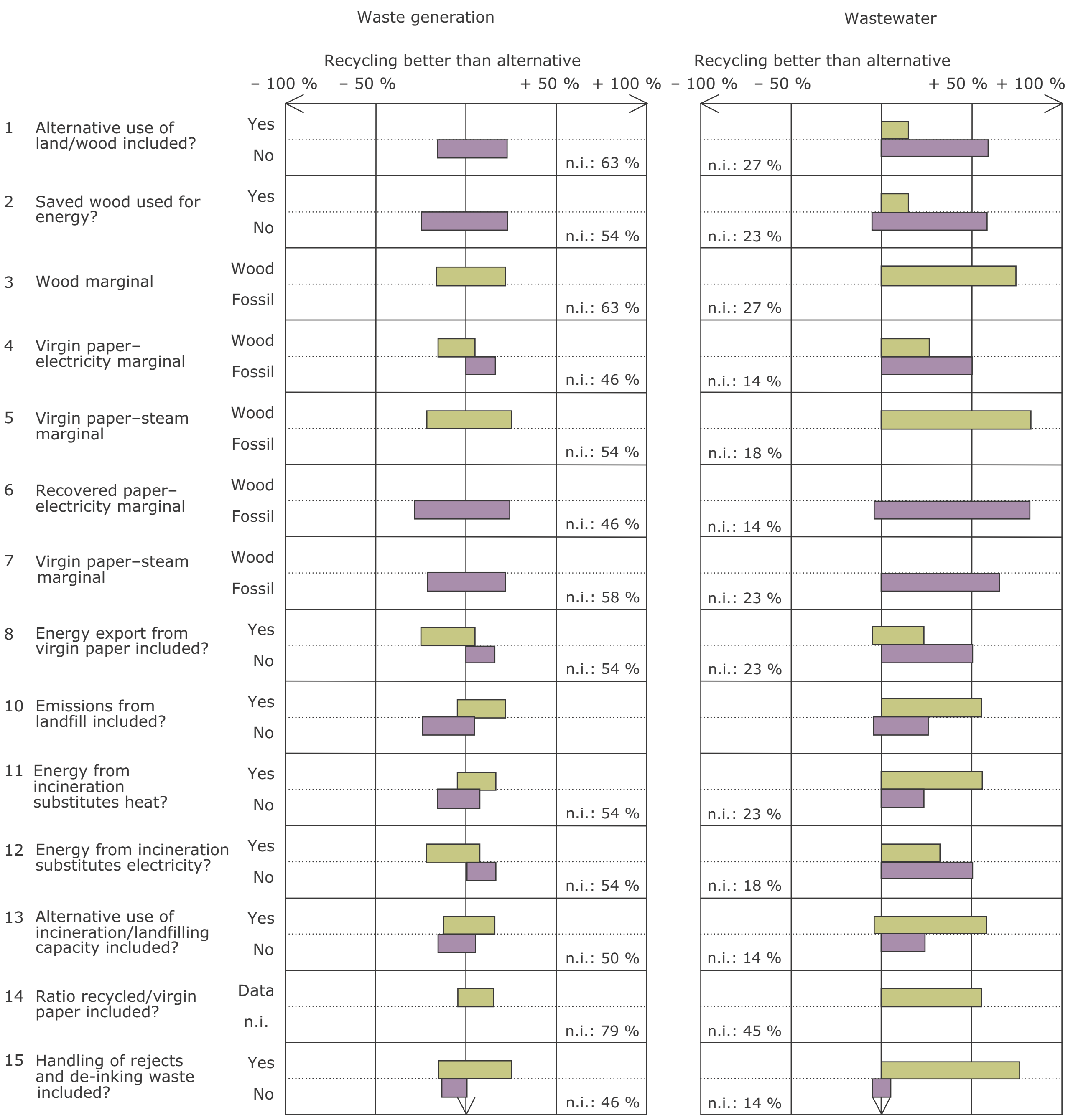


Figure 4.3 Recycling versus incineration, without Study S9 (continued)



most cases, only one scenario (from Study S4) out of the 19 covered contributes with results in this category. In the remaining 18 scenarios, there are unfortunately no results for this impact category (see Annex 5, Table A5.4, indicated as 'n.i.'), and therefore the results of this category are to be taken with caution. The toxicity category in Study S4 is additionally poorly documented, and it is not known if this study has taken into account the short- and long-term (beyond 30 years) toxicity impact potentials derived from landfill leachate emissions, which is believed to be one of the main single causes contributing to toxicity from landfills (Nielsen and Hauschild,1998).

Waste generation

Waste generation is higher in paper landfilling scenarios with no recycling, due to the over-riding contribution of the disposal of paper, which offsets any waste generation in the recycling system such as de-inking sludge, desulphurisation gypsum, slag and ashes generated in energy production from fossil fuels.

There can be additional difficulties for a comparison of waste results which are not purely technical, for example, legislative: the residues from coal combustion (desulphurisation gypsum, slag and ashes) are currently characterised and registered as waste in EU countries, whereas they are by-products in others. Such differences make the comparison of environmental profiles in these categories additionally difficult.

Wastewater

The category 'wastewater' is in most cases heavily dominated by the effect of COD discharges, which are higher from virgin paper production than from recycled paper production. It is very difficult to interpret in the studies the origin of wastewater impacts. For example, in corrugated cardboard recycling, most wastewater COD emissions stem from the dissolution of starch, which is used as a binder to keep the cardboard structure together. The extent to which the studies cover, analyse and document such emissions is very different from study to study.

4.4 Recycling versus incineration

Figures 4.2 and 4.3 illustrate that recycling is clearly more favourable than incineration in the environmental impact categories 'energy use', 'energy-related impacts', 'toxicity' and 'wastewater'. The results from the LCA studies are not clearly in favour of one or the other option in the categories 'non-renewable resource use' and 'waste generation', where there is a strong influence of the 15 key assumptions (discussed in Section 4.5 below). The impact categories considered are reviewed in the following.

Energy use

This category is present and well documented in most of the scenarios. As observed in the comparison with landfilling, recycling of paper uses less energy than virgin paper production and incineration regardless of the choice made in the key assumptions. This robustness is again due to the fact that energy consumption is a function of the technology used for virgin and recycled paper processing and incineration, and to a minor extent to the boundary conditions of the paper system. Figures 4.2 and 4.3 illustrate that the virgin paper cycle uses more energy despite the fact that some energy is obtained from incineration.

Resource consumption

The resources category is very influenced by the definitions of what type of resources are to be included, and from the LCAs analysed it is not possible to say if recycling or incineration has a better environmental profile on this issue. When Study S9 is included, the resources consumption is slightly more frequently lower in paper recycling than in paper incineration.

The comparison is blurred by the lack of transparent specifications of whether resources such as wood and water are of unlimited or limited availability, and if they are included or not under this category. In the studies where wood and water are considered unlimited resources and are not included, most of the consumption of resources are fossil fuels and the chemical additives for paper (e.g. sulphates, lime). In such cases, the results depend on the choice of energy source made (fossil/renewable).

Energy-related impacts

Both Figure 4.2 and Figure 4.3 show that the energy-related impacts are assessed as being lower by paper recycling than by paper incineration in a high number of scenarios, both when Study S9 is included and excluded.

The energy-related impacts depend largely on the energy marginals (both electricity and heat) used for the production of both virgin and recycled paper.

If wood exists in unlimited amounts, and is used as fuel for virgin paper production, whereas fossil fuels are used for recycled paper production, then the overall picture tends to be favourable to the system using virgin paper (see Figures 4.2 and 4.3). If, on the other hand, a mix of wood, fossil fuels and other energy sources are used in both production systems, then paper recycling systems tend to be favoured because of their overall lower energy use.

Toxicity

The results from the toxicity category are characterised by a very low representativeness: in most cases, only few scenarios contribute with results in this category. Therefore, the results of this category are to be taken with caution. Figures 4.2 and 4.3 indicate that the recycling scenarios have lower toxicity impact than incineration scenarios, presumably due to the emission of toxic substances in the virgin paper production processes.

Waste generation

Waste generation is slightly lower in the recycling scenarios if Study S9 is included (Figure 4.2), and very slightly favourable to incineration if this study is excluded (Figure 4.3).

Waste is generated in the incineration system in the form of slag, ashes and desulphurisation gypsum from incineration. This amount is much lower (approximately 10 %) than the equivalent paper volume to be landfilled if there was no incineration. Therefore, the difference with the recycling system is not as clear. The major contribution to waste from paper incineration is from the inorganic chemicals, which leave incineration in the form of ash and slag. This contribution is known to be included in Study S9, but it is unknown whether it is included or not in the other studies.

The results from this category are equally dependent on the assumptions made on the energy sources, which both for wood and for fossil fuel-based combustion result in the generation of desulphurisation gypsum, slag and ashes. Similarly to the description given for landfilling, this category has the additional difficulties derived from the characterisation of coal combustion residues as waste or as by-products.

Wastewater

The category 'wastewater' indicates that emissions are higher from virgin paper production than from recycled paper production. This is clearer in the group of scenarios without Study S9 than in the group that include it.

4.4.1 *Differences between including and excluding Study S9: is there a bias?*

The large amount of scenarios (27) in Study S9 (Frees *et al.*, 2004) has motivated this separate assessment of the rest of the scenarios, which investigates the results of the LCA studies without any bias that might be created by the inclusion of the scenarios from Study S9.

The differences observed between the inclusion and exclusion of the scenarios from Study S9 are in all cases less than 20 %. In most cases except for 'wastewater', where the direction of the bias is the opposite, a bias of 5–10 % is observed by the inclusion of the study towards a favourisation of recycling over incineration. The bias changes the sign of the result only in the category of 'waste generation', where it is very slightly favourable to recycling including the study and slightly favourable to incineration excluding it.

The overall assessment of Figures 4.2 and 4.3 is that recycling is more favourable than incineration in most environmental impact categories considered, although the picture is not as clear when the scenarios from Study S9 are excluded.

In the categories 'energy use', 'energy-related impacts', 'toxicity' and 'wastewater', recycling is clearly more favourable than incineration. The results of the toxicity category, favourable to recycling, are again hampered by the very few scenarios including it. In the categories 'non-renewable resource use' and 'waste generation', where there is a strong influence of the 15 key assumptions, there is no clear picture as to whether incineration or recycling is more favourable environmentally.

4.4.2 *Final comments*

The results presented in this study illustrate that the large majority of analysed LCA scenarios conclude that paper recycling is a better option than either landfilling or incineration in most known environmental impact categories.

This result does not coincide with one of the hypotheses motivating the present study, namely that the results of paper LCA studies were very different. The LCA studies analysed, selected from the existing literature on the basis of a set of quality criteria, arrive at similar results.

This conclusion is an overall result from the 73 scenarios considered. A few of the nine studies analysed arrive at the conclusion that incineration can under certain circumstances be more favourable than recycling. However, the results presented show that the scenarios of the mentioned studies where this occurs are few, require a special combination of assumptions, and are in some cases characterised by the absence of documentation. It is very interesting to observe that in the few cases of impact categories where incineration is more favourable than recycling, a high dependency on the key assumption is observed.

The benefits of recycling are clearly illustrated in the categories of 'energy use', 'energy-related impacts', 'toxicity' (but with low representativeness) and 'wastewater'. However, it is less clear in the categories of 'non-renewable resource consumption' and 'waste generation' due to the dependency on the type of fuel used for energy. If fossil fuels are used in a scenario, then this assumption typically leads to a higher score in non-renewable resource use, and also in waste generation.

The present study is not in a position to give any recommendation on the optimal degree of recycling. Paper fibres become shorter and shorter every time they are recycled, and after a maximum of six or seven times of recycling, fibres eventually become too short for further recycling. It is reasonable to assume that exceeding a certain percentage of use of the shorter recycled fibres in paper reduces dramatically its properties, and makes necessary the use of more paper mass of recycled fibres to obtain a product with equivalent quality and physical properties to a similar but lighter product made of virgin paper.

4.5 Significance of key assumptions on the outcome of the study

The present review allows to a wide extent to identify the significance of the key assumptions on the outcome of any comparative LCA study on paper recycling versus landfilling/incineration. The question to be answered is: to what extent do choices, or lack of choices, on these key issues determine the result of the LCA?

For some of the key assumptions, it is quite clear what is correct to assume and what is incorrect from an LCA methodology point of view. For other assumptions it is less clear, because the assumption depends on the perspective adopted and the probability assigned to the different scenarios for the future.

In the following analysis, the key assumptions are first commented from an LCA methodology point of view. These comments are based on the authors' LCA expertise and are not derived from the present review. Subsequently, the significance of the assumption for the outcome of the study is discussed, based on the results of the present review as presented in Figures 4.1 to 4.3.

4.5.1 Key assumptions in the raw material/forestry stage

Key assumptions 1 and 2: Alternative use of land/wood including use of saved wood for energy

LCA methodology: A probable consequence of paper recycling is a reduction of the demand of virgin paper and consequently a reduced use of land in forestry. As mentioned before, this can be dealt with in an LCA in two ways, either by including land use as an impact category or by expanding the system with an alternative use of the forest land or the equivalent amount of wood harvested from it. From an LCA point of view, one of these ways should be included in order to ensure system equivalence. It is not necessarily clear whether the forest land will just be used less intensively (less wood harvesting and thus more 'uncultivated' forest) or if there will be an alternative use of wood from the land, for example, as fuel for energy purposes. The choice will depend on the type of scenarios for the future to be analysed. These scenarios may include the availability of the various fuel types within the time perspective of the study, and other framework conditions shaped by global, regional and national energy policies, including their influence on fuel prices.

Significance of the assumptions: The assumption taken on this issue is seen to be highly significant. If an alternative use of the forest land or the wood from the forest land is included in the study, the outcome is seen to be almost exclusively in favour of paper recycling for all impact categories (see Figures 4.1 to 4.3). It should be noted, though, that the vast majority of scenarios that do include alternative land use do it as alternative use of the saved wood for energy purposes. As discussed above, uncertainty remains about whether this will be the case or whether saved forest land will just imply a reduction in forest cultivation, that is, a decrease of land use and an increase in uncultivated forest land.

Key assumption 3: Wood marginal

LCA methodology: It is unquestionable that the processes/technologies included in the study should be the marginal ones, in other words, the ones responding to a change in demand. This implies that also consumption of fuels for energy and raw materials should be the marginal ones. Today, wood for paper making is in excess and the use of wood does not happen at the expense of other uses of wood. In scenarios for the future, however, it may be anticipated, as some of the studies do, that wood in the future becomes a priority fuel/raw material of limited availability, be it due to energy policy or to fuel scarcity. The probability of wood becoming of priority and limited availability is difficult to judge, as it will depend on the global environmental situation, environmental policies, availability of alternative energy provision, and so on. Therefore, there is not a right or wrong choice on this assumption. However, the assumption taken should be transparent and justified and the interpretation of results depending on the assumption carefully explained in relation to it. As previously seen, this is seldom the case.

Significance of the assumption: The implication of the assumption on the difference between recycling and landfilling/incineration is the same as for key assumptions 1 and 2, and there is, thus, the same high significance.

4.5.2 Key assumptions in the production stage

Key assumption 4: Virgin paper — electricity marginal

LCA methodology: There is international consensus that LCA in comparative assertions shall include the marginal technologies/processes, in other words, the processes responding to a change in the demand in question. This methodological topic is highly relevant for the electricity consumption of virgin paper, as in many cases this industry draws its electricity from a national grid supplied to a wide extent by hydropower. The production of hydropower and supply to the grid does, however, not respond to a change in demand for paper, even though the paper company draws its electricity from the grid. The reason is that hydropower is of economic priority and limited availability, meaning that the available quantity of power from the dammed water will always be used independently of any paper production increase or decrease. A change in demand for the virgin paper connected to the grid will, instead, result in a change in import or export of electricity and thus a change in fossil fuel-based electricity in neighbouring countries.

Significance of the assumption: The assumption is highly significant, especially for thermo-mechanical pulp and chemical-thermo-mechanical pulp, as these paper types have a relatively high consumption of electricity. Looking at resource consumption and energy related impacts in the comparison between recycling and incineration, (Figures 4.2 and 4.3), it is clear that if it is assumed that hydropower is used for electricity for the manufacture of virgin paper, paper incineration will be favourable. But this is, as discussed above, a wrong assumption. With the correct assumption — the marginal of the electricity being fossil — the picture turns in clear favour of paper recycling, as evident from Figures 4.2 and 4.3.

Key assumption 5: Virgin paper — steam marginal

LCA methodology: The methodological aspects are the same as for electricity (as for any other process). But in this case, it is not clear what is correct. Steam for virgin paper is like the raw materials most often based on wood — only a smaller portion being based on fossil fuel, typically heavy fuel oil. The methodological considerations are, therefore, the same as described under key assumptions 1–3 for wood as raw material, meaning that no clear right or wrong choice exists. It can only be demanded that the assumption is transparently justified and its interpretation is carefully explained.

Significance of the assumption: The assumption is seen to be quite significant, in other words, if fossil fuel is assumed to be the marginal fuel for virgin paper production, there is very clear favour of recycling on all impact categories, whereas if wood is assumed to be the marginal fuel, there are some categories which are in favour of incineration.

Key assumption 6: Recovered paper — electricity marginal

LCA methodology: The same considerations about using electricity marginal in virgin paper are valid. Likewise, there is clearly a right way of doing it. All studies have used fossil fuel-based electricity. It might not be the correct marginal fossil fuel or fossil fuel combination, but the marginal will be some kind of fossil fuel anyway. In this review, in order to keep it simple, it has been chosen to look at fossil fuel in general versus hydropower or wood. It is assumed that the largest implications lie within this choice and not so much within choosing different varieties of fossil fuels, even though the differences between the impacts from different fossil fuels can be very large.

Significance of the assumption: There would be some significance of the choice made on this assumption. However, all studies choose correctly to use fossil fuel-based electricity — probably because the recovery paper companies are located in countries in which the electricity grid is mainly supplied by fossil fuel-based electricity production, so the marginal is not in contradiction with the national average.

Key assumption 7: Recovered paper — steam marginal

LCA methodology: Paper recovery uses, in almost all cases, a fossil fuel for steam production, and in all studies this fossil fuel has been used, which is in accordance with LCA methodology standards.

Significance of the assumption: Due to the uniform use of fossil fuel-based steam, the review does not reveal the significance of the assumption.

Key assumption 8: Energy export from virgin paper production

LCA methodology: In some cases, there is an excess of energy that can be exported to the power grid. In such cases, clearly the avoided alternative energy production should be included in the study. It has not been possible within the review to check whether the paper companies comprised in a certain study actually did or did not export energy, so it is not possible to judge whether the assumptions taken are right or wrong.

Significance of the assumption: It does show, though, that the studies in which an energy export has been included have a tendency towards being more favourable to paper incineration.

Key assumption 15: Handling of rejects and de-inking waste

LCA methodology: Any waste stream should of course be followed to its final interaction with the environment or other systems. If such a stream is incinerated with energy utilisation, the system should be expanded accordingly, if it is composted and utilised on land, any saving on, for example, fertilisers should be included, and if landfilled, any emissions from this should be included. It seems, however, that the majority of studies deal with this correctly.

Significance of the assumption: The assumption does not show any clear significance.

4.5.3 Key assumptions in the disposal stage

Key assumption 10: Emissions from landfill

LCA methodology: Any emissions from landfill should be included. Paper is degraded in landfills, and during the anaerobic digestion both CO_2 and CH_4 are released. Methane has a significantly higher specific contribution to global warming than CO_2,and additionally contributes to photochemical ozone formation, meaning that any degradation that is anaerobic as opposed to aerobic contributes to higher overall impacts. Only a few studies have left out dealing with this, but the assumptions made on the amount of CH_4 released from a landfill are very different between studies.

Significance of the assumption: There is no clear tendency, as the significance of the assumption seems to be over-ruled by the implications of other assumptions.

Key assumption 11: Energy from incineration substitutes heat?

LCA methodology: Any utilisation of the heat value of the paper as heat on the grid should be accounted for in the LCA by including the avoided alternative supply of heat to the grid. Heat from waste incineration plants is, however, not necessarily utilised in all regions, so it is not possible within this review to tell to what extent the inclusion or exclusion of heat utilisation is done correctly or incorrectly. Presumably, when included, it is correct, whereas not including it may be an oversight or it may be correct.

Significance of the assumption: Inherently, it may be of some significance to include heat utilisation taking place during paper disposal, as the heat value of the paper constitutes a high proportion of the energy consumption throughout the paper system. Often, however, heat supply to the grid for district heating is in excess anyhow, due to the co-generation of heat and power from power plants connected to the same grid as waste incineration plants. This means that heat produced by incineration plants does not in reality lead to much saving of alternative heat production. Only very few studies within the review have not included heat utilisation, and it is difficult, based on the results from the review, to draw clear conclusions on the significance of the assumption. In the few studies without the inclusion of heat utilisation, there seems to be a higher tendency to favour incineration, which is contra-intuitive to the fact that heat from incinerating the paper should in fact favour incineration. This indicates that the assumption is not very significant, which is sustained by the theoretical point about heat being difficult to utilise on the grid.

Key assumption 12: Energy from incineration substitutes electricity?

LCA methodology: As above, any conversion of the heat value of the paper into electricity used on the power grid should be accounted for in the LCA by including the avoided alternative supply of electricity to the grid. Conversely to the case of heat, electricity is not necessarily utilised from waste incineration plants, so it is not possible within this review to tell to what extent the inclusion or exclusion of electricity utilisation is done correctly or incorrectly. Presumably, when included, it is correct, whereas not including it may be an oversight or it may be correct.

Significance of the assumption: Inherently, it is of major significance to include electricity utilisation taking place during paper disposal, as the heat value of the paper constitutes a high proportion of the energy consumption throughout the paper system. Electricity supply to the grid, moreover, is not in excess, as heat is. Therefore, any production of electricity from incineration plants is likely to substitute the same amount of electricity from power plants. There is a clear tendency that the scenarios including the utilisation of electricity from incineration plants are more frequently in favour of incineration than scenarios not including electricity utilisation.

Key assumption 13: Alternative use of incineration/landfilling capacity

LCA methodology: In the short term, a release of incineration capacity in waste incineration plants may imply that these plants instead take in other wastes. These wastes would otherwise have been disposed of elsewhere, most probably in landfills due to the pressure to optimise the use of existing incineration capacity. This leads to avoided landfilling and consequently to avoided emissions (or avoided landfill gas utilisation to the extent it is used) from such landfills. This should be included in the LCA. In the longer term, society can be expected to adjust the incineration capacity by further investments, and therefore, any increase or decrease in capacity on existing plants will be levelled out. In the longer term, therefore, the consequence of releasing incineration capacity by further paper recycling is not an avoided landfilling but an avoided investment in new incineration plant capacity (and the related environmental consequences of this).

Significance of the assumption: Inherently, the significance of this assumption is high, because of the aforementioned methane formation on landfills. Moreover, if organic waste from landfills is taken in, not only the emissions from the landfill are avoided, but also emissions from fuels substituted by the organic, and thus CO_2 neutral, fuel that the waste constitutes. The statistics from the review show some tendency that scenarios not including the utilisation of incineration capacity increase are more frequently in favour of paper incineration (see Figure 4.2 on 'waste generation' and Figure 4.3 on 'energy-related impacts' and 'waste generation').

Key assumption 14: Ratio recycled/virgin paper substitution

LCA methodology: Recovered paper does not have the same quality as virgin paper due to the wear and tear on the fibre throughout the life and recovery of the paper. Therefore, one cannot assume that recovered paper substitutes virgin paper in the ratio of 1:1. Moreover, the actual substitution ratio can depend on economic issues and price elasticity between recovered and virgin paper.

Significance of the assumption: The statistics of Figures 4.1 to 4.3 do not allow for an identification of the significance of the assumptions made. Inherently, the assumption is highly significant. Most studies, however, assume a ratio of 1:1 or 1:0.8, so the difference is not large.

4.5.4 *Most essential assumptions in the comparisons*

Recycling versus landfilling

The key assumptions which seem to be the most significant in the recycled versus landfilling comparison are the following.

- Key assumption 1: Alternative use of land/wood
- Key assumption 2: Saved wood used for energy
- Key assumption 3: Wood marginal
- Key assumption 13: Alternative use of incineration and landfilling capacity.

Recycling versus incineration

In some impact categories, the largest differences in the results obtained depend on the following key assumptions.

- Key assumptions 1, 2 and 3: Alternative use of wood and wood marginal
- Key assumption 4: Virgin paper — electricity marginal

- Key assumption 12: Energy from incineration substitutes electricity
- Key assumption 13: Alternative use of incineration capacity.

4.5.5 Geographical or methodological differences?

Most of the differences observed between the LCAs are not due to conscious methodological choices. Rather, the differences observed are due to the unawareness in some of the studies about the need to include and justify certain assumptions in a comparative LCA. The omission of considering and being transparent about these assumptions is an error in the LCA, because it may result in the comparison of two systems which may not be fully comparable.

If two ideal LCAs were made taking into account all the 15 key assumptions mentioned, but in two different geographical locations, this would reduce the differences in some of the key assumptions. The ratio of substitution of recycled/virgin paper could also be taken as the same in both systems for comparison purposes, as well as the level of the technology (e.g. BAT, average technologies). However, there would still be differences in the results, which are exclusively due to geographical differences:

- geographical differences in the sources of energy for electricity and heat production and the energy marginal;
- geographical differences in the waste management structure of two given regions, specific examples being:
    - incineration/landfill capacity;
    - energy (heat, electricity) use from waste incineration;
    - collection of landfill gas and energy generation;
- geographical differences in the alternative use of the forest, its land and the residues from wood extraction.

Nevertheless, an important conclusion from the present study is that the results from the nine studies, produced in different geographical areas, and some of them without having taken into consideration some of the key assumptions mentioned, indicate that recycling has a better environmental profile than landfilling and than incineration.

The present study confirms and highlights results from existing methodological studies (e.g. Ekvall, 1996; Strömberg *et al.,* 1997) suggesting that comparative LCAs on paper management are characterised by a number of important assumptions, even though, as demonstrated here, not all the assumptions seem equally important. Most of these assumptions are also valid for other waste streams, combustible or non-combustible. The omission of these assumptions is a pitfall in the elaboration of such an LCA. The results from the present study can be useful for waste LCA practitioners in the elaboration of future comparative LCAs which analyse waste handling alternatives, and especially used paper. The study highlights the importance of including and justifying the following issues:

- system delimitation, so that secondary streams of sludge, rejects, and wood residues are taken into account;
- identification of secondary services of energy production, forestry services, disposal capacity use and fertilising value;
- time perspective, which influences the type of technologies considered, the choice of the marginals of energy, land use, wood use, disposal capacity and the horizon of the emissions.

Figure 3.3 illustrates graphically the mentioned issues.

All these assumptions that characterise a comparative LCA have to be included, defined, and justified. Otherwise, the LCA can lead to incorrect conclusions. This has implications for the understanding of the use of ISO's LCA standards: to follow the recommendations of the ISO standards is a necessary but not a sufficient condition for producing a high-quality LCA.

It is considered that most geographical boundary conditions, which can potentially influence the result of an LCA, are included in one or more of the 15 assumptions described. Possible exceptions to this are extreme cases of paper system scenarios with very high transportation requirements, like systems where paper is collected from the individual households instead of being collected in larger, centralised containers.

5 Conclusions and outlook

5.1 Conclusions

Most scenarios included in the LCA studies analysed indicate that recycling of waste paper has a lower environmental impact than the alternatives of landfilling or incineration. The result is very clear in the comparison of recycling versus landfilling, and less pronounced but also clear in the comparison of recycling versus incineration.

The results obtained refute one of the hypotheses motivating the present study, namely that the results of existing paper LCA studies were very different. The LCA studies analysed, selected from existing literature on the basis of a set of quality criteria, to a wide extent arrive at similar results. Some differences are observed, however. These differences are not found to be due to actual differences in the environmental impacts from the paper systems studied, but rather to differences in the applied LCA methodology and especially the definition of the paper system and its boundaries. The differences observed in some of the studies, therefore, are not believed to be the result of conscious methodological choices, but rather to unawareness about the need to include and justify certain assumptions in a comparative LCA.

The environmental benefits of recycling are most pronounced in the impact categories 'energy use', 'energy-related impacts' and 'wastewater'. Other impact categories including 'use of resources', 'waste generation' and 'toxicity' are favourable to recycling, but the picture is not as clear. The impact category 'toxicity' is only included in very few scenarios. The information about this category has therefore not the same statistical value as the results from the other impact categories where data from most scenarios exist.

It is also interesting to observe that the results in certain environmental impact categories are more robust than in others with respect to the choice made in the key assumptions. 'Energy use', 'energy-related impacts' and 'wastewater' results are more robust than 'resource consumption' and 'waste generation' results. The robustness of 'energy use' is explained by the fact that energy data are mainly dependent on the type of technology used, and not on the key assumptions of system definition and boundary conditions.

'Resource consumption' and 'waste generation' are categories whose results are very dependent on the fuel mix used for producing the energy that is used in the virgin paper and recycling systems. The results in these categories can be slightly favourable to incineration if wood is used as fuel for virgin paper production and simultaneously coal is used as the only fuel for recycled paper production.

'Toxicity', or 'land use' are also more dependent on the assumptions made in the LCA than 'energy use'. Additionally, obtaining reliable data about these categories can in some cases be difficult.

Additional difficulties for a comparison can be of non-technical nature, for example, legislative: the residues from coal combustion (gypsum, slag and ashes) are currently characterised and registered as waste in EU countries, whereas they are by-products in other countries outside the EU. Such differences make the comparison of environmental profiles in these categories more difficult.

The outcome of a comparative LCA on paper depends on a series of key assumptions, some of which have a high influence on the result. In all, 15 key assumptions have been identified that to a lower or higher degree influence the results and conclusions of the LCA. The most important of these are explained below.

- The assumption of the energy and material marginals for wood, and the alternative uses of wood and forest land. **If** an alternative use of wood other than the use for paper production is included in an LCA, or if wood is considered to have a fossil fuel marginal, all LCA studies analysed show preference to paper recycling no matter what other assumptions were made.
- The assumption of the electricity marginal for virgin paper production. **If** the electricity used for virgin paper production is assumed — as in almost all cases it should be — to be based on fossil fuel and not hydropower, the vast majority of the analysed LCA studies show that paper recycling is more favourable than both landfilling and incineration.
- The assumption of substitution of electricity from incineration of paper. **If** it is assumed that electricity is not produced at waste incineration

plants, and accordingly there is no substitution of grid power, paper incineration almost never turns out to be favourable.
- The assumption of alternative use of incineration capacity. **If** it is assumed that an increase of paper recycling releases some incineration capacity, and it is assumed that this capacity is used to incinerate waste that would otherwise have been landfilled, then in almost all cases analysed this implies that the results of the LCA are in favour of paper recycling.

LCAs on paper depend also on a series of data that are linked to the geographical conditions of the region analysed. It is estimated that most geographical boundary conditions that can potentially influence the result of an LCA, are included in one or more of the 15 assumptions described. The most essential geographical conditions are:

- geographical differences in the sources of energy for electricity and heat production and the energy marginal;
- geographical differences in the waste management structure of two given regions, specific examples of these being:
  - incineration/landfill capacity;
  - energy (heat, electricity) use from waste incineration;
  - collection of landfill gas and energy generation;
- geographical differences in the alternative use of the forest, its land and the residues from wood extraction.

Nevertheless, an important conclusion from the present study is that the results from the nine studies, produced in different geographical areas, and including to different degrees the key assumptions mentioned, indicate that recycling results in less environmental impacts than landfilling and incineration. It is not an excluded hypothesis that a location may exist where the combination of energy supply marginals (and not only averages) is such that incineration is a better alternative than recycling from an environmental standpoint. However, no such case has been found in the LCA studies reviewed.

The results from the present study do not provide information that can be used to recommend an optimal ratio of recycling. Paper fibres become shorter and shorter every time they are recycled, and after a number of times of recycling, fibres eventually become too short for further recycling. Finding an environmentally optimal recycling rate requires a study which among other variables analyses also in depth the quality of paper and its manufacturing technology.

5.2 Outlook

Environmental decision-making tools and decision-support tools: LCA and CBA

LCA and CBA are both methods used to analyse systems and supply information that can be used for decision-making.

A **decision-making tool** is a method that allows to quantify two or more originally non-quantifed concepts (e.g. 'total environmental impact' or 'cost to society'), and thereby reduces a decision to the more simple choice between two magnitudes or numbers.

A **decision-support tool** is based on the same principle of quantification of non-quantified concepts, but it is more modest in its ambitions: instead of aiming at being the basis for the decision, it aims at bringing some information that can then be used, together with other information, to take the decision.

Decision-support tools are important instruments in the definition of environmental policies, and are able to analyse the existing information about a given field and present it in a form that is useful for decision-making. No decision-support tool is unaffected by error, and therefore it is important to bear in mind that these tools can create the best conditions possible for decision-making, but also have their limitations.

All currently available decision-support tools have to deal with the uncertainty of the data sources (e.g. emissions to air and to water), as well as the causal relationships used to convert these data into quantifiable variables used for decision-making. In order to reduce the risk of taking wrong decisions because of uncertain data, most decision-support tools require a sensitivity analysis to assess the uncertainty. Both the LCA and CBA methodologies include these.

LCA and CBA

LCA and CBA are two examples of decision-support tools, even though sometimes the goals and ambitions of LCAs and especially of CBAs are excessively large, and in some cases can be presented as ultimate tools for decision-making.

LCAs and CBAs help to create the best conditions possible for decision-making, but as exemplified here, they also have their limitations.

The purpose of CBA is to optimise the social benefit derived from an action, by weighting the environmental and economic consequences of the action. This objective is much more ambitious than in an LCA, where the objective is limited to characterise the environmental impact of an action.

An LCA is therefore more modest than a CBA, in the sense that it is limited to the environmental and technical sphere, whereas a CBA encompasses this sphere and part of the social and economic spheres. A CBA aims at covering all the relevant environmental and economic consequences of an action, and refers it to monetary units, which are easy to use in decision-making. Such simplification, combined with the ambitious scope, gives additional uncertainties and lack of transparency to the process compared with an LCA, and a CBA is therefore more prone to misinterpretation or even misuse.

The LCA and CBA methodologies have in common some of the steps they consist of. However, while most of the steps in an LCA have been through a process of international standardisation, this is not the case with the CBA methodology.

Both methodologies have to tackle the problems of lack of information, in particular about the interdependency of systems and their causal–effect chains, reflected for instance in the record of emissions and secondary services. This absence of perfect information creates uncertainties, and adds a risk to the decisions being made on this basis. Both the LCA and CBA methodologies require a sensitivity analysis to assess the uncertainties.

Another crucial condition for the reliability of the result of using a decision-support tool is the transparency of the process and the possibility to trace back into the data sources and assumptions of the study. Lack of transparency obstructs an independent review of the results, and can make it impossible to correct corrupted results or assumptions. The transparency of the process is also fundamental for understanding the limitations of the method used. The international standards for LCA include the requirement of an external review.

Both CBAs and LCAs face the challenge of comparing normally non-comparable variables, and therefore arrive at a point where some subjectivity has to be used. State-of-the-art LCAs do this comparison by using politically defined targets on, for example, emissions, resource use or biodiversity, which allows a prioritisation between them. CBAs compare by using monetary units, for instance using 'willingness to pay' principles. The use of monetary units is particularly difficult and controversial for magnitudes that normally do not have an economic

Table 5.1 Summary of the main conclusions from the non-LCA studies

Type of statement of the conclusions	Reference
Mostly favourable to incineration	Danish Institute for Environmental Assessment (2002)
Favourable to incineration under certain boundary conditions (e.g. paper type, percentage collection, incineration efficiency, geography, population density, other)	Berglund (2003)
	Ekvall and Bäckman (2001b)
	Leach *et al.* (1997)
No specific/definite conclusions concerning comparison of treatment options	Environmental Defence (1995)
	European Commission (1998)
	European Commission (2000b)
	Sundin *et al.* (1998)
Favourable to recycling under certain boundary conditions (e.g. paper type, percentage collection, incineration efficiency, geography, population density, other)	Baumgärtner and Winkler (2003)
	Bergsma (2001)
	Broom et al. (2000)
	Dalager et al. (1995)
	European Commission (2000a)
	European Commission (2003)
	Grieg-Gran (1999)
Mostly favourable to recycling	Wenzel (2003)
	Friends of the Earth (1998)
	MacGuire (1997)

value on a market, for instance, the value of an unspoiled landscape or of the consequences of lead emissions from cars.

LCAs and CBAs on paper

A general screening of the non-LCAs (including several CBAs) collected in literature has been carried out. The references included in the screening have different objectives, starting points and very different methodologies. Therefore it has been difficult to present within this study a comprehensive overview of their results and conclusions. An in-depth comparison of the studies is a comprehensive task, which is beyond the scope of the present study. An attempt to summarise the main conclusions concerning comparison of different management options of waste paper/cardboard is presented in Table 5.1.

Compared with the conclusions observed in the LCAs, the results from these non-LCA studies are more spread-out than the LCAs. Some of the studies found seem to be in favour of recycling, some in favour of incineration. The authors of these studies often find no absolute justification for recommending any particular management option, when taking into account also financial variables of waste management and incorporating environmental costs and benefits in their analyses. Few studies make categorical conclusions about the issue, and most of them arrive at soft conclusions, very dependent on the set of assumptions taken.

The methodological difficulties are reflected in the fact that a majority of the studies acknowledge the limitations of the economic tools used as a basis for decision support, and focus on a description of the uncertainties and the boundary conditions rather than on the result.

It is suggested as a challenging future activity to complete the literature list of non-LCAs of the present study, and investigate in detail the results and methodological implications of these non-LCAs, similarly to the activities carried out with the LCAs.

Annex 1: Complete list of LCA references

Methodology studies (cardboard and paper)

De Groot, A., Ekvall, T., Backlund, B., Dobson, P., Svensson, G. (1998). *LCA methodology in the pulp and paper industry 1. Cradle to gate inventory analysis*. A report from the LCA working group within COST Action E1, July 1998.

Ekvall, T. (1996). *Key issues in the assessment of wood fibre flows*. 1996:1, Nordpap/DP2/20. CIT Ekologik, Chalmers Industriteknik, Gothenburg, Sweden.

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Ekvall, T. (1999b). *System expansion and allocation in life cycle assessment — With implications for wastepaper management institution*. Dissertation, Chalmers University of Technology, Gothenburg, Sweden.

Ekvall, T. (2000). 'Life cycle assessments of paper and board recycling'. In: *Proceedings 4th Int. Conf. on Env. Imp. of the Pulp and Paper Ind.* Helsinki, Finland, pp. 71–76.

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Annex 2: Complete list of contacts established with institutions in Europe

Belgium	• VITO
Denmark	• IPU-Institute for Product Development • COWI Consulting • dk-Teknik Energy & Environment • IPL — The Department of Manufacturing Engineering and Management, Technical University of Denmark • LCA 2.-0 Consultants • Niras
Finland	• Finnish Environment Institute • Finnish Forest Industries Federation • Jaakko Pöyry Oyj • KCL, Finnish Pulp and Paper Research Institute • University of Helsinki • VTT Industrial Systems
France	• CARAT Environnement • Ecobilan • Eco-conception conseils • O2 France
Germany	• TU Dresden- Institut für Abfallwirtschaft und Altlasten • CAU GmbH • Five Winds International • GesPaRec • IFEU-Institut für Energie- und Umweltforschung • IÖW • ISO-Institut Köln • LCE Consulting GmbH • Ökoinstitut • PE Engineering
Greece	• Aristotle University, Thessaloniki Laboratory of Heat Transfer and Environmental Engineering
Italy	• Ecobilancio • Febe EcoLogic • Life Cycle Engineering (LCE) • Seconda Università degli Studi di Napoli
Netherlands	• CE Delft • IVAM • PRé Consultants • TNO Bouw
Norway	• Elopak • STØ — Østfold Research Foundation
Portugal	• INETI — The National Institute of Industrial Engineering and Technology
Spain	• Randa Group

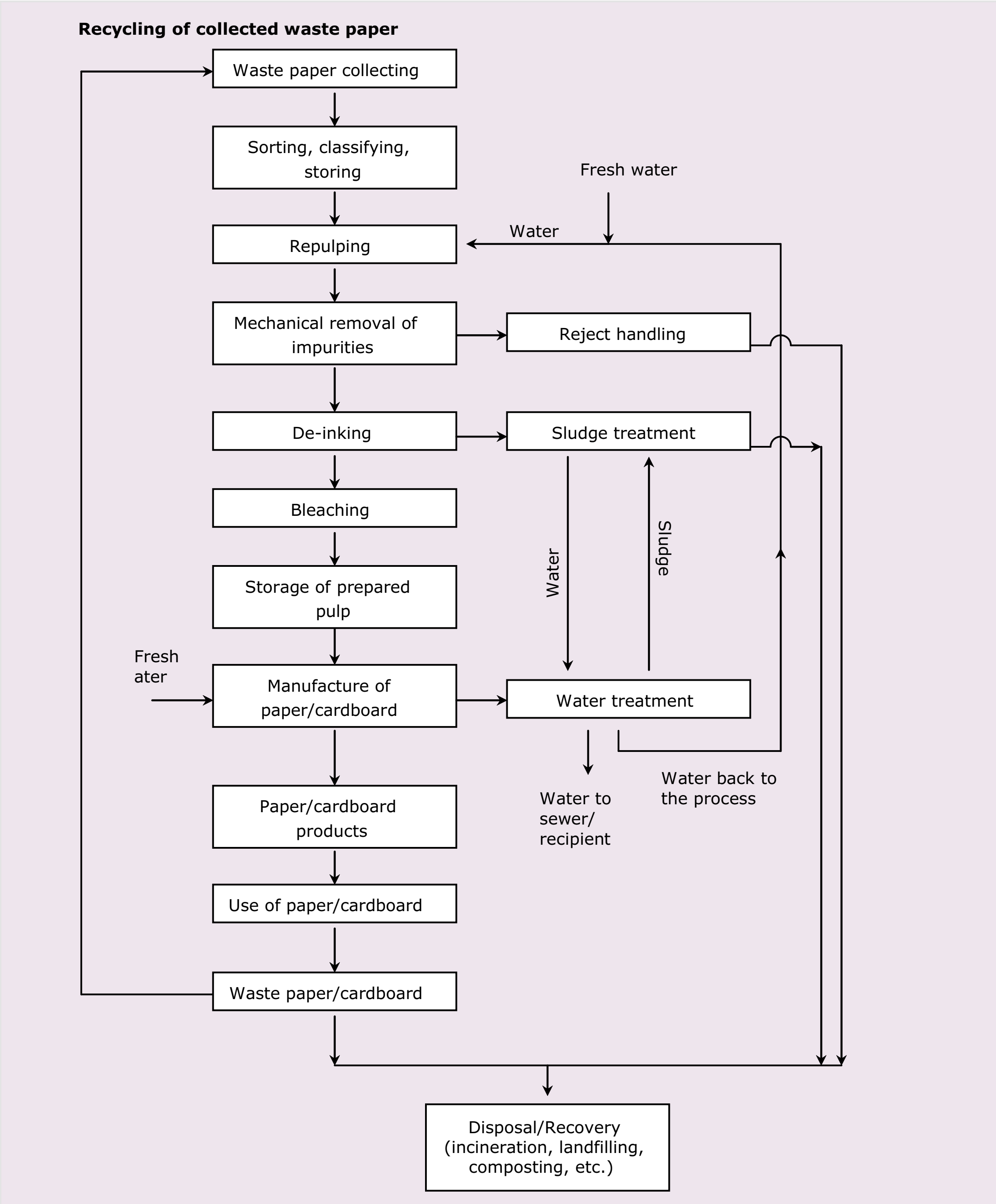
Sweden	• CIT Ekologik AB, Chalmers Industriteknik • CEPI Eurokraft, European Kraft Paper Producers for the Flexible Packaging Industry • Chalmers University of Technology, Environmental Systems Analysis • Chalmers University of Technology, Physical Resource Theory • Framkom — The Swedish Research Institute for Media Technology • Högskolan Dalarna • IVL — Swedish Environmental Research Institute • Karlstad University, Department of Environmental and Energy Systems • Skogforsk — The Forestry Research Institute of Sweden • Packforsk — The Swedish Institute for Packaging and Logistics • STFI — The Swedish Pulp and Paper Research Institute • Stora Enso • Trätek — The Swedish Institute for Wood Technology Research
Switzerland	• Doka Oekobilanzen • EcoIntegra • ESU services • Sustainable Asset Management
United Kingdom	• Boustead Consulting • CSERGE — Centre for Social and Economic Research on the Global Environment at the University of East Anglia • EuGeos Limited • University of Surrey, Centre for Environmental Strategy • PIRA International

Annex 3: Description of the processing of used paper

The steps involved in the manufacturing process of used paper are described below, and are illustrated in Figure A3.1.

Generally, recycled fibre processes can be divided in two main categories (European Commission, 2001; Bilitewski *et al.*, 2000):

Figure A3.1 The manufacturing process of used paper



- processes with exclusively mechanical cleaning, that is, without de-inking, comprising products like testliner, corrugating medium, board and cardboard;
- processes with mechanical and chemical unit processes, that is, with deiinking. They comprise products like newsprint, tissue, printing and copy paper, magazine papers (lightweight coated paper), some grades of cardboard or market de-inked pulp.

The design of the processing lines depends on the collected waste paper grade to be processed and on the paper or board grade to be produced.

The main task of a collected waste paper preparation line is the removal of contaminants. There is a large variety of them ranging from stones, metal pieces, glass fragments and plastics to minerals and printing inks. Some of these contaminants can cause damage to the subsequent machinery equipment, whereas other impurities affect the optical performance of recycled fibres and of recycled fibre containing paper.

Another important task of collected waste paper processing aims at an upgrading of the recycled fibres to compensate for declining quality, resulting from fibre shortening and reduced strength affected by previous papermaking.

Collection and storage of waste paper

For effective use of collected waste paper it is necessary to collect, sort and classify the materials into suitable quality grades. Therefore, after collection waste paper is brought to the collection yards where it is sorted. Detrimental substances such as plastics, laminated papers and so on are removed before baling as well as possible. The sorted paper is usually compacted by baling machines. Industrial collected waste paper from large generators is usually delivered to and processed in collected waste paper yards integrated in the paper mill in the form of bales kept together by metal wires or straps. The bales are opened by cutting the wires or straps that are collected and sold as metal waste. To some mills collected waste paper is also delivered as loose material in big containers or by bulk dumping.

Repulping of the collected waste paper

The paper is put into a pulper together with water, and pulped with agitation resulting in disintegration into fibres. After repulping, collected waste paper has a consistency for subsequent treatment. Some chemicals are often added as pulping additives. Contaminants and clusters are removed continuously during operation and are sent to a reject conveyor, in order to avoid the contaminants breaking into small pieces or accumulating in the pulper. There is an increasing use of secondary pulpers for further defibration and cleaning from heavyweight and lightweight dirt.

Mechanical removal of impurities

The removal of mechanical impurities is based on the differences in physical properties between fibres and contaminants, such as size, specific gravity compared with fibres and water. Basically there is screen-type equipment and various types of hydrocyclones (high consistency cleaners, centrifugal cleaners, etc.).

The partially cleaned pulp slurry is pumped from the pulper to high-density cleaners in which centrifugal forces remove smaller heavy weight particles. The rejects of these cleaners as well as of the pulper disposal system usually have to be disposed of by landfilling (high content of inorganic material).

The next process stage is screening to separate contraries, which are larger than the openings of the perforated screens. The reject has to be deposited or further treated.

Depending on the quality to be achieved the plant for collected waste paper processing has to be equipped with additional machines such as fractionators, dispergers or refiners.

A fractionator separates the pulp in two fractions rendering it possible to treat short and long fibres of the pulp slurry in different manners. The energy demanding process of disperging can be performed in order to achieve improved fibre-to-fibre bonding (better strength characteristics) in the paper produced and to reduce visible dirty specks in size. A stock preparation plant can be optionally equipped also with refiners to improve optical and strength characteristics of the paper.

It has to be pointed out that in practice each plant is individually equipped with machines of one or several suppliers, depending on the collected waste paper grades used, the demands of the final product quality, the producing capacity of the paper machine and on local conditions regarding environmental issues.

These process stages described above are applied to the processing of 'brown' stock intended for the manufacturing of case making material. In the case of wood-containing stock for manufacturing newsprint and tissue, the same process stages can be applied, but additionally the following stages are required.

Processes with flotation de-inking

Ink removal is necessary in plants manufacturing paper grades where brightness is important, for example, for newsprint, printing and writing paper, tissue or light topliner of recovered paper-based cardboards. The main objectives of de-inking are increasing of brightness and cleanliness and reduction of stickies. It should be noted that the difference between de-inked and non-de-inked grades is in the process and not in the product itself. Depending on the quality of the recovered paper used, market requirements or production needs, and also packaging papers and boards could be de-inked.

A complete de-inking plant includes also the abovementioned basic unit operations repulping, screening and cleaning for removal of coarse contaminants (non-paper items such as stones, sand, metal, string, glass, textiles, wood, plastic foils, paper clips, etc.). Additionally to mechanical cleaning a chemical pre-treatment of the pulp and a removal of printing inks in flotation cells is carried out. A prerequisite for successful de-inking is that the ink particles are released from the fibres and kept in dispersion. For this purpose de-inking chemicals like NaOH, soaps or fatty acids and so on, are added mostly already in the pulping sequence. The dispersed ink particles are then separated from the fibre slurry by means of (multi-stage) flotation techniques. Ink froth and rejects are dewatered separately in a centrifuge or wire press type equipment up to 50 % of dry substance. De-inking sludge is incinerated or landfilled.

After de-inking the pulp is thickened and sometimes washed using sieve belt presses, thickeners, screw presses, and washers. After these cleaning steps, the pulp may still contain small residual impurities, such as remains of printing ink particles, wax or stickies, which originate, for example, from hot-melt glues and so forth. These impurities can be dispersed so finely with a disperser that the particles are invisible to the naked eye.

Processes with wash de-inking and ash removal

Flotation de-inking is efficient for particle sizes from 5 to 100 µm. Smaller ink particles can be removed by wash de-inking which is basically a multi-stage dewatering. Besides inks, fillers and fine impurities are removed by washing. Washing is often carried out in several stages. Coated papers are especially sensitive to impurities and require very clean pulp. Therefore, a modern de-inking plant for preparation of collected waste paper to lightweight coated paper includes often both flotation and washing de-inking as they complement each other. If ash removal is required as for tissue paper or for market de-inked pulp the system must always include a washing stage.

Bleaching

Before entering a storage tower the pulp is often bleached by use of bleaching chemicals, for example, hydrogen peroxide or hydrosulphite. Bleaching chemicals are added directly in the disperger to maintain or increase the brightness. The reaction itself takes place in a bleaching tower ensuring a sufficient dwell time.

Finally the pulp is pumped to the storage chests or mixing chests. These chests serve as a buffer between the stock preparation and the actual paper machine, to promote process continuity. In the mixing chests the required additives are added and the correct fibre consistency is adjusted for proper sheet-forming in the paper machine.

Process water purification

Water from the dewatering stages may be clarified in a micro-flotation unit. The process water is then re-used in the process. The micro-flotation unit gives a sludge that is thickened and landfilled or incinerated. In case of washing de-inking the total water usage is reduced by recycling the wash water as well. Solids have to be removed from the filtrate by a separate flotation unit.

Final cleaning and dewatering

Different types of fine screens and cleaners remove residual contaminants before the highly diluted pulp slurry is fed to the paper machine. Dewatering/thickening may be done by disc filters and screw presses to achieve the pulp consistency needed as well as to keep the white water loops separated.

Reject and sludge handling

In the processing of recovered paper various types of rejects and sludge in varying quantities are collected and have to be handled. These are pre-treated in the special system and finally landfilled or incinerated with energy recovery. A reduction in the quantity of residues to be disposed of can be achieved if similar types of rejects from various process steps in the stock preparation and the approach flow system are collected and treated together. Fibre recovery also contributes to minimising the quantity of residues.

Annex 4: Summary matrices of the analysed LCA studies

	Scoring system used	
Symbol used	**Magnitude of the difference**	
+++	> 50 %	The scenario is environmentally better than the reference in a given impact category
++	25 to 50 %	
+	5 to 25 %	
0	– 5 to 5 %	Small or no difference
–	– 5 to – 25 %	The scenario is environmentally worse than the reference in a given impact category
–	– 25 to – 50 %	
–	< – 50 %	
n.i.	No information	

Below is a list of studies covered by the matrices.

S1 — Tillman *et al.* (1991)
Tillman, A. M., Baumann, H., Eriksson, E., Rydberg, T. (1991). Life cycle analyses of selected packaging materials. Quantification and environmental loadings. Offprint from *Miljön och förpackningarna*, SOU, 1991:76.

S2 — Dalager *et al.* (1995a–95d)
Dalager *et al.* (1995a–95d). *Miljøøkonomi for papir- oq papkredsløb* (Environmental economics of paper and cardboard circulation. Part 1: Method description, material flow, and references). Arbejdsrapport fra Miljøstyrelsen, No 28–31, Miljøstyrelsen (Danish EPA), Copenhagen, Denmark (in Danish): http://www.mst.dk/udgiv/Publikationer/1995/87-7810-353-3/pdf/87-7810-353-3.pdf.

S3 — Virtanen and Nilsson (1993)
Virtanen, Y., Nilsson, S. (1993). *The environmental impacts of waste paper recycling*. IIASA, Laxembourg (Austria).

S4 — Kärnä *et al.* (1994)
Kärnä, A., Engström, J., Kutinlahti, T., and Pajula, T. (1994). 'Life cycle analysis of newsprint: European scenarios'. *Paperi ja Puu — Paper and Timber*, 76(4): pp. 232–237.

S5 — Ecobalance UK (1998)
Ecobalance UK (1998). *Newsprint — A life cycle study*. An independent assessment of the environmental benefits of recycling at Aylesford Newsprint compared to incineration. Aylesford Newsprint Ltd, Aylesford, United Kingdom: http://www.aylesford-newsprint.co.uk/pdf/lcs.pdf.

S6 — Grant *et al.* (2001)
Grant, T., James, K., Lundie, S., and Sonneveld, K. (2001). *Stage 2 report for life cycle assessment for paper and packaging waste management scenarios in Victoria*. Melbourne, EcoRecycle Victoria. Australia: http://www.ecorecycle.vic.gov.au/asset/1/upload/Stage_2_Report_for_Life_Cycle_Assess_for_Packaging_Waste_Mg.pdf.

S7 — Tiedemann *et al.* (2001)
Tiedemann, A., Klöpffer, W., Grahl, B., and Hamm, U. (2001). *Life cycle assessments for graphic papers*. No 2/2001, Umweltbundesamt, German Federal Environmental Agency, Berlin, Germany: http://www.umweltbundesamt.de/uba-info-medien-e/mysql-media-detail.php3?Kennummer=1925.

S8 — Environmental Defence (2002)
Environmental Defence (2002). *Life cycle environmental comparison — Virgin paper and recycled paper-based systems*. Paper task force, White Paper No 3. Environmental Defence, New York, USA: http://www.environmentaldefense.org/documents/1618_WP3.pdf.

S9 — Frees *et al.* (2004)
Frees, N., Hansen, M. S., Ottosen, L. M., Tønning, K., Wenzel, H. (2004). *Opdatering af vidensgrundlaget for de miljømæssige forhold ved genanvendelse af papir og pap* (Update of the knowledge basis on the environmental impact of paper and cardboard recycling). Submitted for publication in February 2004 to the Danish Environmental Protection Agency within the series 'Environmental Report' (in Danish).

Study	**S1 — Tillman *et al.* (1991)**
Decision to support	Characterise the environmental profile of the life cycle of different products, including corrugated board and paper board for packaging liquids
Functional unit	Life cycle of 1 kg of corrugated board, 93 % dry matter Life cycle of 1 kg of paper board for packaging liquids, 93 % dry matter

Scenarios			**Scenario S1-1 Recycling versus 100 % to landfill**	**Scenario S1-2 Recycling versus 100 % to incineration**	**Scenario S1-3 Recycling versus 100 % to landfill**	**Scenario S1-4 Recycling versus 100 % to incineration**
			Corrugated board	**Corrugated board**	**Paper board for packaging liquids**	**Paper board for packaging liquids**
System boundaries						
Raw materials/ forestry	1	Alternative use of land/wood included?	n.i.	n.i.	n.i.	n.i.
	2	Saved wood used for energy?	No	No	No	No
	3	Wood marginal	n.i.	n.i.	n.i.	n.i.
Paper production	4	Virgin paper • Electricity marginal	Wood + fossil Swedish average	Wood + fossil Swedish average	Wood + fossil Swedish average	Wood + fossil Swedish average
	5	• Steam marginal	n.i.	n.i.	n.i.	n.i.
	6	Recovered paper • Electricity marginal	Fossil	Fossil	Fossil	Fossil
	7	• Steam marginal	n.i.	n.i.	n.i.	n.i.
	8	Energy export from virgin paper included?	Yes	Yes	Yes	Yes
Disposal	9	Main alternative to recycling	Landfill	Incineration	Landfill	Incineration
	10	Emissions from landfill included?	No, only partial energy generation from biogas	No	No, only partial energy generation from biogas	No
	11	Energy from incineration substitutes heat?	n.i.	n.i.	n.i.	n.i.
	12	Energy from incineration substitutes electricity?	n.i.	n.i.	n.i.	n.i.
	13	Alternative use of incineration capacity included?	No	No	No	No
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	0	n.i.	0	n.i.
	15	De-inking sludge considered?	No	No	No	No
Impact assessment — recycling better than disposal?						
Energy			++	++	0	–
Resource consumption	Fossil fuels		n.i.	n.i.	n.i.	n.i.
	Others		n.i.	n.i.	n.i.	n.i.
Energy-related impacts ([1])			SO_2: +++ NO_X: ++ CO_2: ++	SO_2: +++ NO_X:++ CO_2: +++	SO_2: ++ NO_X:0 CO_2: ++	SO_2: +++ NO_X: + CO_2: +++
Toxicity			n.i.	n.i.	n.i.	n.i.
Waste			+++	–	++	–
Other (e.g. biodiversity, wastewater impacts)		Wastewater:	Wastewater: COD: – TSS: –	Wastewater: COD: – TSS: –	Wastewater: COD: + (starch from cardboard) TSS: –	Wastewater: COD: + (starch from cardboard) TSS: –

([1]) Global warming, acidification, nutrient enrichment, tropospheric ozone formation. CH_4 from anaerobic biodegradation not included.

Study	S2 — Dalager *et al*. (1995)
Decision to support	Evaluate the environmental performance of increased paper recycling
Functional unit	Recovery/disposal under different scenarios of the Danish production of used paper, 1995

Scenario			**Increased re-use**				**Reduced re-use**	
			Scenario S2-1	**Scenario S2-2**	**Scenario S2-3**	**Scenario S2-4**	**Scenario S2-5**	**Scenario S2-6**
Sub-scenario			**Increased re-use and reduced incineration — excluding use of saved wood**	**Increased re-use and reduced landfilling — excluding use of saved wood**	**Increased re-use and reduced incineration — including use of saved wood**	**Increased re-use and reduced landfilling — including use of saved wood**	**Reduced re-use and increased**	**Reduced re-use and increased landfilling**
Paper/pulp type			**Corrugated cardboard**	**Corrugated cardboard**	**Corrugated cardboard**	**Corrugated cardboard**	**Corrugated cardboard**	**Corrugated cardboard**
System boundaries								
Raw mat./ forestry	1	Alternative use of land/ wood included?	No	No	Yes	Yes	No	No
	2	Saved wood used for energy?	No	No	Yes	Yes	No	No
	3	Wood marginal	Wood	Wood	Wood	Wood	Wood	Wood
Paper production	Virgin paper							
	4	Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	5	Steam marginal	Wood	Wood	Wood	Wood	Wood	Wood
	Recovered paper							
	6	Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	7	Steam marginal	Fossil/straw	Fossil/straw	Fossil/straw	Fossil/straw	Fossil/straw	Fossil/straw
	8	Energy export from virgin paper included?	No	No	No	No	No	No
Disposal	9	Main alternative to recycling	Incineration	Landfilling	Incineration	Landfilling	Incineration	Landfilling
	10	Emissions from landfill included?	Yes	Yes	Yes	Yes	Yes	Yes
	11	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes	Yes	Yes
	12	Energy from incineration substitutes electricity?	No	No	No	No	No	No
	13	Alternative use of incin-eration capacity included?	No	Yes	No	Yes	No	No
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	0.8	0.8	0.8	0.8	0.8	0.8
	15	De-inking sludge included?	Yes	Yes	Yes	Yes	Yes	Yes
Impact assessment — recycling better than disposal?								
Energy			++	+++	++	+++	++	+++
Resource consumption			–	–	++	+++	–	-
Energy-related impacts			–	++	++	++	+	+
Toxicity			n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Waste			0	++	n.i.	n.i.	0	+
Other (wastewater impacts)			+++	+++	+++	+++	++	++

Scenario			Increased re-use				Reduced re-use	Export	
			Scenario S2-7	**Scenario S2-8**	**Scenario S2-9**	**Scenario S2-10**	**Scenario S2-11**	**Scenario S2-12**	**Scenario S2-13**
Sub-scenario			**Increased re-use and reduced incineration — excluding use of saved wood**	**Increased re-use and reduced landfilling — excluding use of saved wood**	**Increased re-use and reduced incineration — including use of saved wood**	**Increased re-use and reduced landfilling — including use of saved wood**	**Reduced re-use and increased incineratiuon**	**Increased re-use and increased export**	**Reduced re-use and reduced export**
Paper/pulp type			**Newspapers and magazines**	**Newspapers and magazines**	**Newspapers and magazines**	**Newspapers and magazines**	**Newspapers and magazines**	**Newspapers and magazines**	**Newspapers and magazines**
System boundaries									
Raw mat./ forestry	1	Alternative use of land/wood included?	No	No	Yes	Yes	No	No	No
	2	Saved wood used for energy?	No	No	Yes	Yes	No	No	No
	3	Wood marginal	Wood	Wood	Wood	Wood	Wood	Wood	Wood
Paper production	Virgin paper								
	4	Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	5	Steam marginal	Wood	Wood	Wood	Wood	Wood	Wood	Wood
	Recovered paper								
	6	Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	7	Steam marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	8	Energy export from virgin paper included?	No	No	No	No	No	No	No
Disposal	9	Main alternative to recycling	Incineration	Land-filling	Incineration	Land-filling	Incineration	Incineration	Incineration
	10	Emissions from landfill included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	11	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	12	Energy from incineration substitutes electricity?	No	No	No	No	No	No	No
	13	Alternative use of incineration capacity included?	No	Yes	No	Yes	No	No	No
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	15	Disposal of de-inking sludge included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Impact assessment — recycling better than disposal via incineration/landfilling? (Disposal option as indicated in row 9 for each column)									
Energy			+++	+++	+++	+++	+++	+++	+++
Resource consumption			+++	+++	+++	+++	+++	+++	+++
Energy-related impacts			++	+++	+++	+++	+++	+++	+++
Toxicity			n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Waste			+	++	n.i.	n.i.	+	+	+
Other (wastewater impacts)			++	++	++	++	++	++	++

Scenario			**Increased re-use**				**Reduced re-use**
			Scenario S2-14	**Scenario S2-15**	**Scenario S2-16**	**Scenario S2-17**	**Scenario S2-18**
Sub-scenario			**Increased re-use and reduced incineration — excluding use of saved wood**	**Increased re-use and reduced landfilling — excluding use of saved wood**	**Increased re-use and reduced incineration — including use of saved wood**	**Increased re-use and reduced landfilling — including use of saved wood**	**Reduced re-use and increased incineratiuon**
Paper/pulp type			**Mixed paper**	**Mixed paper**	**Mixed paper**	**Mixed paper**	**Mixed paper**
System boundaries							
Raw mat./ forestry	1	Alternative use of land/ wood included?	No	No	Yes	Yes	No
	2	Saved wood used for energy?	No	No	Yes	Yes	No
	3	Wood marginal	Wood	Wood	Wood	Wood	Wood
Paper production	Virgin paper						
	4	Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil
	5	Steam marginal	Wood	Wood	Wood	Wood	Wood
	Recovered paper						
	6	Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil
	7	Steam marginal	Fossil	Fossil	Fossil	Fossil	Fossil
	8	Energy export from virgin paper included?	No	No	No	No	No
Disposal	9	Main alternative to recycling	Incineration	Landfilling	Incineration	Landfilling	Incineration
	10	Emissions from landfill included?	Yes	Yes	Yes	Yes	Yes
	11	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes	Yes
	12	Energy from incineration substitutes electricity?	No	No	No	No	No
	13	Alternative use of incin-eration capacity included?	No	Yes	No	Yes	No
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	0.8	0.8	0.8	0.8	0.8
	15	Disposal of de-inking sludge included?	Yes	Yes	Yes	Yes	Yes
Impact assessment — recycling better than disposal via incineration/landfilling (disposal option as indicated in row 9 for each column)?							
Energy			++	+++	++	+++	+
Resource consumption			–	–	++	+++	–
Energy-related impacts			0	++	++	+++	0
Toxicity			n.i.	n.i.	n.i.	n.i.	n.i.
Waste			0	++	n.i.	n.i.	0
Other (wastewater impacts)			+++	+++	+++	+++	++

Study	**S3 — Virtanen and Nilsson (1993)**
Decision to support	Decision to support: comparison of total incineration versus maximum recycling (56 %)
Functional unit	Not defined

Scenarios			**Scenario S3-1**
			Maximum recycling (56 %) versus maximum incineration
Paper type			**Mixture of 20 % newsprint, 38 %printing and writing, 20 % liner board, 15 % fluting, 7 % folding boxboard, 1 % household**
System boundaries			
Raw materials/ forestry	1	Alternative use of land/wood included?	n.i.
	2	Saved wood used for energy?	n.i.
	3	Wood marginal	n.i.
Paper production	4	Virgin paper — Electricity marginal	Wood + fossil (European mix)
	5	— Steam marginal	Wood
	6	Recovered paper — Electricity marginal	Fossil, European mix
	7	— Steam marginal	Fossil, European mix
	8	Energy export from virgin paper included?	n.i.
Disposal	9	Main alternative to recycling	100 % incineration
	10	Emissions from landfill included?	Yes
	11	Energy from incineration substitutes heat?	Yes, but substitutes heat in pulp + paper process
	12	Energy from incineration substitutes electricity?	Yes, 35 % efficiency
	13	Alternative use of incineration capacity included?	No
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	0.55
	15	De-inking sludge considered?	No
Impact assessment — recycling better than disposal?			
Energy			–
Resource consumption	Fossil fuels		–
	Others		+++
Energy-related impacts ([1])			SO_2:– NO_X:– CO_2:– CH_4:+++
Toxicity			n.i.
Waste			–
Other (e.g. biodiversity, wastewater impacts)			Wastewater: BOD:0 COD:++ TSS:– AOX:+++

([1]) Equal composition of waste paper in the different countries. Emission inventories are incomplete. Only simplified sensitivity analysis.

Study	**S4 — Kärnä *et al*. (1994, 1995)**
Decision to support	Paper re-use versus paper incineration to reduce landfilling
Functional unit	1 000 kg paper/yr delivered to consumers in Germany, 1990. Virgin paper imported from Finland

Scenarios			**Scenario S4-1**	**Scenario S4-2**
			Recycling versus incineration, with a high collection rate (60 %)	**Recycling versus incineration, with a high collection rate (52 %)**
Paper/cardboard type			**Newsprint**	**Magazines**
System boundaries				
Raw materials/ forestry	1	Alternative use of land/wood included?	n.i.	n.i.
	2	Saved wood used for energy?	n.i.	n.i.
	3	Wood marginal	n.i.	n.i.
Paper production	4	Virgin paper — Electricity marginal	Wood/average electricity in Finland (2)	Wood/average electricity in Finland (2)
	5	— Steam marginal	Wood	Wood
	6	Recovered paper — Electricity marginal	Average in Germany (2)	Average in Germany (2)
	7	— Steam marginal	n.i.	n.i.
	8	Energy export from virgin paper included?	n.i.	n.i.
Disposal	9	Main alternative to recycling	Landfill (3)	Incineration (3)
	10	Emissions from landfill included?	Yes, a third of potential	Yes, a third of potential
	11	Energy from incineration substitutes heat?	No	No
	12	Energy from incineration substitutes electricity?	33 % efficiency	33 % efficiency
	13	Alternative use of incineration capacity included?	n.i.	n.i.
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	1 (3)	1 (3)
	15	De-inking sludge considered?	Yes	Yes
Impact assessment — recycling better than disposal via incineration (disposal option as indicated in row 9)?				
Energy			+	
Resource consumption		Fossil fuels	–	0
		Others	n.i.	n.i.
Energy-related impacts (1)			SO_2:– (4) NO_X: 0 GWGases:– VOC: +	SO_2:0 (4) NO_X: 0 GWGases: 0 VOC: 0
Toxicity			n.i.	n.i.
Waste			–	++
Other (e.g. biodiversity, wastewater impacts)		Wastewater	Wastewater: COD:0 AOX	Wastewater: COD:0 AOX:+

Note: No information is given on the weighting factors used and the background of the interpretation of results.

(1) Global warming, acidification, nutrient enrichment, tropospheric ozone formation. CH_4 from anaerobic biodegradation also included.

(2) Average energy generation in Finland, 1990, but no marginal study. Average energy generation in Germany, 1990, but no marginal study.

(3) The mass balance of the recycling of paper is not described. Feeding and sinks of the system missing.

(4) No information on chemicals.

Study	S5 — Ecobalance UK (1998) (commissioned by Aylesford recycling-ANL, United Kingdom)
Decision to support	Paper re-use in the United Kingdom versus paper incineration in the United Kingdom and recycling in other countries (the study adopts the perspective of the recycling company, Aylesford, UK)
Functional unit	Disposal of 1 000 kg used newspapers and magazines

Scenarios			**Scenario S5-1**
			Recycling in Aylesford, United Kingdom, and energy supply to the electricity grid
Paper/cardboard type			**Newsprint**
System boundaries			
Raw materials/ forestry	1	Alternative use of land/wood included?	n.i.
	2	Saved wood used for energy?	n.i.
	3	Wood marginal	Wood. Presumably from ANL distribution countries (2)
Paper production	4	Virgin paper — Electricity marginal	Wood (data from Sweden)
	5	— Steam marginal	Wood (data from Sweden)
	6	Recovered paper — Electricity marginal	Grid: United Kingdom/the country of origin of waste paper (2) No marginal included.
	7	— Steam marginal	n.i.
	8	Energy export from virgin paper included?	n.i.
Disposal	9	Main alternative to recycling	Incineration in United Kingdom and recycling in other countries (***)
	10	Emissions from landfill included?	No
	11	Energy from incineration substitutes heat?	n.i.
	12	Energy from incineration substitutes electricity?	Yes. 25 % efficiency
	13	Alternative use of incineration capacity included?	no (3)
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	n.i.
	15	De-inking waste included?	Yes (incinerated)
Impact assessment — recycling in the United Kingdom better than disposal (incineration, as indicated in the alternative reference of row No 9)?			
Energy			++
Resource consumption		Fossil fuels	Overall:– – (natural gas) +++ (other fuels)
		Other	++ (wood) ++ (water)
Energy-related impacts (1)			SO_2:++ NO_x:++ CO_2: ++ CH_4:++
Toxicity			n.i.
Waste			n.i.
Other (e.g. biodiversity, wastewater impacts)		Wastewater	Wastewater: COD:++ N: +++ P:–

Note: ISO 14000 series is followed.

(1) Acidification, nutrient enrichment, tropospheric ozone formation.

(2) Eleven countries in line with current UK consumption, including Sweden, Norway, Finland, USA, Canada, Germany, the Netherlands, France, Belgium, Spain, Russia.

(3) No indication in the reference scenario (with no incineration in the United Kingdom) of what is the alternative to recycling in the other countries (landfill or incineration).

No sensitivity analysis carried out.

Study	S6 — Grant *et al*. (2001) LCA of paper and packaging waste management scenarios in Victoria
Decision to support	Evaluate the environmental performance of paper recycling versus landfilling (no scenario with incineration)
Functional unit	Management of the recyclable fraction of newsprint paper and board packaging from the average Melbourne household in one week (ca. 3.64 kg on average)

Scenarios			Scenario S6-1 — full degradation of carbon to CH_4 and CO_2; 30 % recycling and landfill (70 %) versus 100 % landfill	Scenario S6-2 — 22 % degradation of carbon to CH_4 and CO_2; 30 % recycling and landfill (70 %) versus 100 % landfill	Scenario S6-3 — full degradation of carbon to CH_4 and CO_2; 30 % recycling and landfill (70 %) versus 100 % landfill	Scenario S6-4 — 22 % degradation of carbon to CH_4 and CO_2; 30 % recycling and landfill (70 %) versus 100 % landfill
Paper/cardboard type			**Newsprint**	**Newsprint**	**Carboard packaging**	**Carboard packaging**
System boundaries						
Raw materials/ forestry	1	Alternative use of land/wood included?	No	No	No	No
	2	Saved wood used for energy?	No	No	No	No
	3	Wood marginal	Fossil	Fossil	Fossil	Fossil
Paper production	4	Virgin paper — Electricity marginal	Fossil. Average in SE Australia.	Fossil. Average in SE Australia.	Fossil. Average in SE Australia.	Fossil. Average in SE Australia.
	5	— Steam marginal	Wood/fossil	Wood/fossil	Wood/fossil	Wood/fossil
	6	Recovered paper — Electricity marginal	Fossil. Average in SE Australia.	Fossil. Average in SE Australia.	Fossil. Average in SE Australia.	Fossil. Average in SE Australia.
	7	— Steam marginal	Fossil	Fossil	Fossil	Fossil
	8	Energy export from virgin paper included?	n.i.	n.i.	n.i.	n.i.
Disposal	9	Main alternative to recycling	100 % landfilling	100 % landfilling	100 % landfilling	100 % landfilling
	10	Emissions from landfill included?	Yes, 100 % of carbon to CH_4 and CO_2	Yes, 22 % of carbon to CH_4 and CO_2	Yes, 100 % of carbon to CH_4 and CO_2	Yes, 22 % of carbon to CH_4 and CO_2
	11	Energy from incineration substitutes heat?	No (no incineration)	No (no incineration)	No (no incineration)	No (no incineration)
	12	Energy from incineration substitutes electricity?	No (no incineration)	No (no incineration)	No (no incineration)	No (no incineration)
	13	Alternative use of incineration capacity included?	No (no incineration)	No (no incineration)	No (no incineration)	No (no incineration)
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	0	0.75	0	0.75
	15	De-inking sludge included?	Yes	Yes	Yes	Yes
Impact assessment — recycling better than disposal via incineration/landfilling (disposal option as indicated in row 9 for each column)?						
Energy			+	+++	+	+++
Resource consumption	Fossil fuels		n.i.	n.i.	n.i.	n.i.
	Others		Water: +++	Water:+++	Water:+++	Water:+++
Energy-related impacts (1)			GWG: +++	GWG:–	GWG: +++	GWG:+++
Toxicity			n.i.	n.i.	n.i.	n.i.
Waste			+++	+++	+++	+++
Other (e.g. biodiversity, wastewater impacts)			Trophospheric smog formation:+++	Trophospheric smog formation:+++	Trophospheric smog formation:+++	Trophospheric smog formation:+++

Note: Several different allocation methods have been used reviewed by CML, Netherlands.
GWG: global warming gas emissions.

(1) Global warming, acidification, nutrient enrichment, tropospheric ozone formation. CH_4 from anaerobic biodegradation also included.

Study	S7 — Tiedemann *et al*. (2001) Environmental comparison of recycling and disposal processes of used graphic paper and newsprint
Decision to support	Find the disposal option(s) with lower environmental impacts
Functional unit	Total production and processing of paper in Germany in 1995

			Scenario S7-1	Scenario S7-2	Scenario S7-3	Scenario S7-4	Scenario S7-5	Scenario S7-6
Sub-scenario			**Increased recycling — main scenario**	**Decreased recycling — main scenario**	**Unchanged recycling — incineration versus landfill**	**Decreased recycling — incineration scenario**	**Increased versus decreased recycling — incineration scenario**	**Increased recycling — saved wood used for energy**
Paper/pulp type			**Graphic paper**	**Graphic paper**	**Graphic paper**	**Graphic paper**	**Graphic paper**	**Graphic paper**
System boundaries								
Raw mat./ forestry	1	Alternative use of land/wood included?	No	No	No	No	No	Yes
	2	Saved wood used for energy?	No	No	No	No	No	Yes
	3	Wood marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
Paper production	Virgin paper							
	4	Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	5	Steam marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	Recovered paper							
	6	Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	7	Steam marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
	8	Energy export from virgin paper included?	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Disposal	9	Main alternative to recycling	30/70 inc./ land	30/70 inc./ land	Incineration	Incineration	Incineration	30/70 inc./ land
	10	Emissions from landfill included?	Yes	Yes	Yes	Yes	Yes	Yes
	11	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes	Yes	Yes
	12	Energy from incineration substitutes electricity?	Yes	Yes	Yes	Yes	Yes	Yes
	13	Alternative use of incineration capacity included?	No	No	No	No	No	No
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	0.8–1.0	0.8–1.0	0.8–1.0	0.8–1.0	0.8–1.0	0.8–1.0
	15	Disposal of de-inking sludge included?	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Impact assessment — recycling better than disposal via incineration/landfilling (disposal option as indicated in row 9 for each column)?								
Energy			n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Resource consumption			++	++	++	++	+	++
Energy-related impacts			+++	+++	+++	–	+	+++
Toxicity			+	+	+	0	0	0
Waste			n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Other			+++	+++	n.i.	++	+++	n.i.

Study	S9 — Frees *et al*. (2004) Update of the knowledge basis on the environmental impact of paper and cardboard recycling
Decision to support	Update of information about paper recycling and disposal
Functional unit	In the scenarios with 100 % recycling and 100 % incineration: 1 kg of paper/board collected in Denmark in year 2001. In the other scenarios: total use of paper in Denmark in 2001

Scenario			**Biomass unlimited — alternative use of land/wood for energy**									
Sub-scenario			**Scenario S9-10**		**Scenario S9-11**	**Scenario S9-12**	**Scenario S9-13**	**Scenario S9-14**	**Scenario S9-15**	**Scenario S9-16**	**Scenario S9-17**	**Scenario S9-18**
			Base case		**Alternative use of incineration capacity**	**Only heat production from incineration — no electricity**	**Base case**	**Alternative use of incineration capacity**	**Only heat production from incineration — no electricity**	**Base case**	**Alternative use of incineration capacity**	**Only heat production from incineration — no electricity**
Paper/pulp type			**Mixed paper**		**Mixed paper**	**Mixed paper**	**Newspapers and magazines**	**Newspapers and magazines**	**Newspapers and magazines**	**Corrugated cardboard**	**Corrugated cardboard**	**Corrugated cardboard**
System boundaries												
Raw mat./forestry	1	Alternative use of land/wood included?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
	2	Saved wood used for energy?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
	3	Wood marginal	Wood	Wood	Wood	Wood		Wood	Wood	Wood	Wood	Wood
Paper production		Virgin paper										
	4	Electricity marginal	Fossil	Fossil	Fossil	Fossil		Fossil	Fossil	Fossil	Fossil	Fossil
	5	Steam marginal	Wood	Wood	Wood	Wood		Wood	Wood	Wood	Wood	Wood
		Recovered paper										
	6	Electricity marginal	Fossil	Fossil	Fossil	Fossil		Fossil	Fossil	Fossil	Fossil	Fossil
	7	Steam marginal	Fossil	Fossil	Fossil	Fossil		Fossil	Fossil	Fossil	Fossil	Fossil
	8	Energy export from virgin paper included?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Disposal	9	Main alternative to recycling	Incineration	Incineration	Incineration	Incineration		Incineration	Incineration	Incineration	Incineration	Incineration
	10	Emissions from landfill included?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
	11	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
	12	Energy from incineration substitutes electricity?	Yes	Yes	No	Yes		Yes	No	Yes	Yes	No
	13	Alternative use of incineration capacity included?	No	Yes	No	No		Yes	No	No	Yes	No
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	0.8	0.8	0.8	0.8		0.8	0.8	0.8	0.8	0.8
	15	Disposal of de-inking sludge included?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Impact assessment — recycling better than disposal via incineration/landfilling (disposal option as indicated in row 9 for each column)?												
Energy			++	+++	+++	+++		+++	+++	++	+++	+++
Resource consumption			+++	+++	+++	+++		+++	+++	+++	+++	+++
Energy-related impacts (1)			+++	+++	+++	+++		+++	+++	+++	+++	+++
Toxicity			n.i.	n.i.	n.i.	n.i.		n.i.	n.i.	n.i.	n.i.	n.i.
Waste			+++	+++	+++	+++		–	+++	+	–	+
Other			n.i.	n.i.	n.i.	n.i.		n.i.	n.i.	n.i.	n.i.	n.i.

Scenario			Biomass unlimited — alternative use of land/wood for energy									
Sub-scenario			Scenario S9-10		Scenario S9-11	Scenario S9-12	Scenario S9-13	Scenario S9-14	Scenario S9-15	Scenario S9-16	Scenario S9-17	Scenario S9-18
			Base case		Alternative use of incineration capacity	Only heat production from incineration — no electricity	Base case	Alternative use of incineration capacity	Only heat production from incineration — no electricity	Base case	Alternative use of incineration capacity	Only heat production from incineration — no electricity
Paper/pulp type			Mixed paper		Mixed paper	Mixed paper	Newspapers and magazines	Newspapers and magazines	Newspapers and magazines	Corrugated cardboard	Corrugated cardboard	Corrugated cardboard
System boundaries												
Raw mat./forestry	1	Alternative use of land/wood included?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
	2	Saved wood used for energy?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
	3	Wood marginal	Wood	Wood	Wood	Wood		Wood	Wood	Wood	Wood	Wood
Paper production		Virgin paper										
	4	Electricity marginal	Fossil	Fossil	Fossil	Fossil		Fossil	Fossil	Fossil	Fossil	Fossil
	5	Steam marginal	Wood	Wood	Wood	Wood		Wood	Wood	Wood	Wood	Wood
		Recovered paper										
	6	Electricity marginal	Fossil	Fossil	Fossil	Fossil		Fossil	Fossil	Fossil	Fossil	Fossil
	7	Steam marginal	Fossil	Fossil	Fossil	Fossil		Fossil	Fossil	Fossil	Fossil	Fossil
	8	Energy export from virgin paper included?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Disposal	9	Main alternative to recycling	Incineration	Incineration	Incineration	Incineration		Incineration	Incineration	Incineration	Incineration	Incineration
	10	Emissions from landfill included?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
	11	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
	12	Energy from incineration substitutes electricity?	Yes	Yes	No	Yes		Yes	No	Yes	Yes	No
	13	Alternative use of incineration capacity included?	No	Yes	No	No		Yes	No	No	Yes	No
	14	In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	0.8	0.8	0.8	0.8		0.8	0.8	0.8	0.8	0.8
	15	Disposal of de-inking sludge included?	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Impact assessment — recycling better than disposal via incineration/landfilling (disposal option as indicated in row 9 for each column)?												
Energy			++	+++	+++	+++		+++	+++	++	+++	+++
Resource consumption			+++	+++	+++	+++		+++	+++	+++	+++	+++
Energy-related impacts (1)			+++	+++	+++	+++		+++	+++	+++	+++	+++
Toxicity			n.i.	n.i.	n.i.	n.i.		n.i.	n.i.	n.i.	n.i.	n.i.
Waste			+++	+++	+++	+++		–	+++	+	–	+
Other			n.i.	n.i.	n.i.	n.i.		n.i.	n.i.	n.i.	n.i.	n.i.

(*) Global warming, acidification, nutrient enrichment, tropospheric ozone formation. CH_4 from anaerobic biodegradation also included.

Scenario	Biomass limited — wood marginal = fossil fuel								
	Scenario S9-19	Scenario S9-20	Scenario S9-21	Scenario S9-22	Scenario S9-23	Scenario S9-24	Scenario S9-25	Scenario S9-26	Scenario S9-27
Sub-scenario	Base case	Alternative use of incineration capacity	Only heat production from incineration — no electricity	Base case	Alternative use of incineration capacity	Only heat production from incineration — no electricity	Base case	Alternative use of incineration capacity	Only heat production from incineration — no electricity
Paper/pulp type	Mixed paper	Mixed paper	Mixed paper	Newspapers and magazines	Newspapers and magazines	Newspapers and magazines	Corrugated cardboard	Corrugated cardboard	Corrugated cardboard
System boundaries									
Raw mat./forestry — 1 Alternative use of land/wood included?	No	No	No	No	No	No	No	No	No
Raw mat./forestry — 2 Saved wood used for energy?	No	No	No	No	No	No	No	No	No
Raw mat./forestry — 3 Wood marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
Paper production — Virgin paper									
4 Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
5 Steam marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
Recovered paper									
6 Electricity marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
7 Steam marginal	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil	Fossil
8 Energy export from virgin paper included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Disposal — 9 Main alternative to recycling	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration	Incineration
10 Emissions from landfill included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
11 Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
12 Energy from incineration substitutes electricity?	Yes	Yes	No	Yes	Yes	No	Yes	Yes	No
13 Alternative use of incineration capacity included?	No	Yes	No	No	Yes	No	No	Yes	No
14 In which ratio does recycled paper substitute virgin paper (1:1 or 1:0.8 or 1:0.5 or other)?	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
15 Disposal of de-inking sludge included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Impact assessment — recycling better than disposal via incineration/landfilling (disposal option as indicated in row 9 for each column)?									
Energy	++	+++	+++	+++	+++	+++	++	+++	+++
Resource consumption	++	+++	+++	+++	+++	+++	+++	+++	+++
Energy-related impacts (1)	+++	+++	+++	+++	+++	+++	+++	+++	+++
Toxicity	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.
Waste	+++	+++	+++	+++	++	+++	+++	+++	+++
Other	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.	n.i.

(1) Global warming, acidification, nutrient enrichment, tropospheric ozone formation. CH_4 from anaerobic biodegradation also included.

Annex 5: Result tables

Table A5.1 Distribution of the 73 scenarios according to the 15 assumptions

Code	System boundary conditions		Number of scenarios	Codes of the scenarios included in the different categories
1	Alternative use of land/wood included?	Yes	6+1+9=16	(S2-3), (S2-4), (S2-9), (S2-10), (S2-16), (S2-17), (S7-6), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18)
		No	12+4+5+10+9+9=49	(S2-1), (S2-2), (S2-5), (S2-6), (S2-7), (S2-8), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-18), (S6-1), (S6-2), (S6-3), (S6-4), (S7-1), (S7-2), (S7-3), (S7-4), (S7-5), (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		n.i.	4+1+2+1=8	(S1-1), (S1-2), (S1-3), (S1-4), (S3-1), (S4-1), (S4-2), (S5-1)
2	Saved wood used for energy?	Yes	6+1+9=16	(S2-3), (S2-4), (S2-9), (S2-10), (S2-16), (S2-17), (S7-6),(S7-6), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18)
		No	4+12+4+5+10+9+9=53	(S1-1), (S1-2), (S1-3), (S1-4), (S2-1), (S2-2), (S2-5), (S2-6), (S2-7), (S2-8), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-18),(S6-1), (S6-2), (S6-3), (S6-4),(S7-1), (S7-2), (S7-3), (S7-4), (S7-5), (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10),(S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		n.i.	1+2+1=4	(S3-1), (S4-1), (S4-2), (S5-1)
3	Wood marginal	Wood	18+10+18=46	(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18),(S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18)
		Fossil	4+6+9=19	(S6-1), (S6-2), (S6-3), (S6-4), (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6),(S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		n.i.	4+1+2+1=8	(S1-1), (S1-2), (S1-3), (S1-4), (S3-1),(S4-1), (S4-2), (S5-1)
4	Virgin paper — Electricity marginal	Wood	1+10=11	(S5-1),(S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10)
		Fossil	18+4+6+18+9=55	(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18), (S6-1), (S6-2), (S6-3), (S6-4),(S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		Mix wood/ fossil	4+1+2=7	(S1-1), (S1-2), (S1-3), (S1-4),(S3-1), (S4-1), (S4-2)
		n.i.	0	
5	— Steam marginal	Wood	18+1+2+1+10+18=50	(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18),(S3-1), (S4-1), (S4-2),(S5-1),(S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18)
		Fossil	4+6+9=19	(S6-1), (S6-2), (S6-3), (S6-4), (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		n.i.	4	(S1-1), (S1-2), (S1-3), (S1-4)

Code	System boundary conditions		Number of scenarios	Codes of the scenarios included in the different categories
6	Recovered paper — Electricity marginal	Wood	0	
		Fossil	4+18+1+2+1+4+6+10+18+9=73	(S1-1), (S1-2), (S1-3), (S1-4),(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18),(S3-1), (S4-1), (S4-2), (S5-1),(S6-1), (S6-2), (S6-3), (S6-4), (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6), (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		n.i.	0	
7	— Steam marginal	Wood	0	
		Fossil	12+1+4+6+10+18+9=60	(S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18), (S3-1),(S6-1), (S6-2), (S6-3), (S6-4), (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6),(S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		Mix wood/ fossil	6	(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6)
		n.i.	4+2+1=7	(S1-1), (S1-2), (S1-3), (S1-4), (S4-1), (S4-2),(S5-1)
8	Energy export from virgin paper included?	Yes	4+10+27=41	(S1-1), (S1-2), (S1-3), (S1-4), (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		No	18	(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18)
		n.i.	1+2+1+4+6=14	(S3-1), (S4-1), (S4-2), (S5-1), (S6-1), (S6-2), (S6-3), (S6-4), (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6)
9	Main alter-native to recycling	Incine-ration	2+11+1+1+1+3+5+27=51	(S1-2), (S1-4), (S2-1), (S2-3), (S2-5), (S2-7), (S2-9),(S2-11), (S2-12), (S2-13), (S2-14), (S2-16), (S2-18), (S3-1), (S4-2), (S5-1), (S7-3), (S7-4), (S7-5), (S8-2), (S8-4), (S8-6), (S8-8), (S8-10) (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27),
		Land-filling	2+7+1+4+5=19	(S1-1), (S1-3), (S2-2), (S2-4), (S2-6), (S2-8),(S2-10), (S2-15), (S2-17), (S4-1), (S6-1), (S6-2), (S6-3), (S6-4), (S8-1), (S8-3), (S8-5), (S8-7), (S8-9)
		30 inc/70 landfill	3	(S7-1), (S7-2), (S7-6)
10	Emissions from landfill included?	Yes	18+1+2+4+6+27=58	(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18) (S3-1) (S4-1) (S4-2) (S6-1), (S6-2), (S6-3), (S6-4), (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		No	4+1+10=15	(S1-1), (S1-2), (S1-3), (S1-4) (S5-1),(S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10),
11	Energy from incineration substitutes heat?	Yes	18+1+6+27=52	(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18) (S3-1) (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		No	2+4+10=16	(S4-1), (S4-2), (S6-1), (S6-2), (S6-3), (S6-4) (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10)
		n.i.	4+1=5	(S1-1), (S1-2), (S1-3), (S1-4), (S5-1)

Code	System boundary conditions		Number of scenarios	Codes of the scenarios included in the different categories
12	Energy from incineration substitutes electricity?	Yes	1+2+1+6+10+18=38	(S3-1),(S4-1), (S4-2), (S5-1), (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6), (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-1), (S9-2), (S9-4), (S9-5), (S9-7), (S9-8), (S9-10), (S9-11), (S9-13), (S9-14), (S9-16), (S9-17), (S9-19), (S9-20), (S9-22), (S9-23), (S9-25), (S9-26),
		No	18+4+9=31	,(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18) (S6-1), (S6-2), (S6-3), (S6-4) (S9-3), (S9-6), (S9-9),(S9-12), (S9-15), (S9-18), (S9-21), (S9-24), (S9-27)
		n.i.	4+	(S1-1), (S1-2), (S1-3), (S1-4)
13	Alternative use of incineration/landfilling capacity included?	Yes	6+10+9=25	,(S2-2), (S2-4), (S2-8), (S2-10), (S2-15), (S2-17), (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-2), (S9-5), (S9-8), (S9-11), (S9-14), (S9-17), (S9-20), (S9-23), (S9-26)
		No	4+12+1+1+4+6+18=46	(S1-1), (S1-2), (S1-3), (S1-4), (S2-1), (S2-3), (S2-5), (S2-6), (S2-7), (S2-9), (S2-11), (S2-12), (S2-13), (S2-14), (S2-16), (S2-18) (S3-1) (S5-1) (S6-1), (S6-2), (S6-3), (S6-4) (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6) (S9-1), (S9-3), (S9-4), (S9-6), (S9-7), (S9-9), (S9-10), (S9-12), (S9-13), (S9-15), (S9-16), (S9-18), (S9-19), (S9-21), (S9-22), (S9-24), (S9-25), (S9-27)
		n.i.	2	(S4-1) (S4-2)
14	In which ratio does recycled paper substitute virgin paper?	Data (1:1 or 1:0.8 or 1:0.5 or other)	2+18+1+4+6+27=58	(S1-1), (S1-3), (S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18) (S3-1) (S6-1), (S6-2), (S6-3), (S6-4) (S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6) (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27),
		n.i.	2+2+1+10=15	(S1-2), (S1-4), (S4-1) (S4-2) (S5-1) (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10)
15	De-inking sludge included?	Yes	18+2+1+4+10+27=62	(S2-1), (S2-2), (S2-3), (S2-4), (S2-5), (S2-6), (S2-7), (S2-8), (S2-9),(S2-10), (S2-11), (S2-12), (S2-13), (S2-14), (S2-15), (S2-16), (S2-17), (S2-18) (S4-1) (S4-2) (S5-1) (S6-1), (S6-2), (S6-3), (S6-4) (S8-1), (S8-2), (S8-3), (S8-4), (S8-5), (S8-6), (S8-7), (S8-8), (S8-9), (S8-10), (S9-1), (S9-2), (S9-3), (S9-4), (S9-5), (S9-6), (S9-7), (S9-8), (S9-9), (S9-10), (S9-11), (S9-12), (S9-13), (S9-14), (S9-15), (S9-16), (S9-17), (S9-18), (S9-19), (S9-20), (S9-21), (S9-22), (S9-23), (S9-24), (S9-25), (S9-26), (S9-27)
		No	4+1=5	(S1-1), (S1-2), (S1-3), (S1-4), (S3-1)
		n.i.	6	(S7-1), (S7-2), (S7-3), (S7-4), (S7-5),(S7-6)

Table A5.2 Distribution of results of the environmental impact of recycling versus incineration, 51 scena

Code	System boundary conditions		Number of scenarios	Energy +++	Energy ++	Energy +	Energy 0	Energy -	Energy - -	Energy - - -	Energy n.i	Resource consumption +++	Resource consumption ++	Resource consumption +	Resource consumption 0	Resource consumption -	Resource consumption - -	Resource consumption - - -	Resource consumption n.i	Energy related impa +++	Energy related impa ++	Energy related impa +	Energy related impa 0
1	Alternative use of land/wood included?	Yes	12	8	4	0	0	0	0	0	0	10	2	0	0	0	0	0	0	10	2	0	0
		No	34	20	8	3	0	0	0	0	3	13	5	2	3	1	6	4	0	17	3	4	4
		n.i.	5	0	2	0	0	2	0	1	0	0	0	0	1	0	1	1	2	2	2	0	1
2	Saved wood used for energy?	Yes	12	8	4	0	0	0	0	0	0	10	2	0	0	0	0	0	0	10	2	0	0
		No	36	20	9	3	0	1	0	0	3	13	5	2	3	1	6	4	2	19	3	4	4
		n.i.	3	0	1	0	0	1	0	1	0	0	0	0	1	0	1	1	0	0	2	0	1
3	Wood marginal	Wood	34	21	10	3	0	0	0	0	0	15	4	1	3	1	6	4	0	17	5	3	4
		Fossil	12	7	2	0	0	0	0	0	3	8	3	1	0	0	0	0	0	10	0	1	0
		n.i.	5	0	2	0	0	2	0	1	0	0	0	0	1	0	1	1	2	2	2	0	1
4	Virgin paper	Wood	6	1	3	2	0	0	0	0	0	0	0	0	1	0	3	2	0	0	2	0	1
	- Electricity marginal	Fossil	41	27	10	1	0	0	0	0	3	23	7	2	2	1	4	2	0	27	4	4	3
		Mix wood/fossil	4	0	1	0	0	2	0	1	0	0	0	0	1	0	0	1	2	2	1	0	1
		n.i.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Virgin paper	Wood	37	21	11	3	0	1	0	1	0	15	4	1	4	1	7	5	0	17	7	3	5
	- Steam marginal	Fossil	12	7	2	0	0	0	0	0	3	8	3	1	0	0	0	0	0	10	0	1	0
		n.i.	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
6	Recovered paper	Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	- Electricity marginal	Fossil	51	28	14	3	0	2	0	1	3	23	7	2	4	1	7	5	2	29	7	4	5
		n.i.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Recovered paper - Steam marginal	Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	- Steam marginal	Fossil	44	28	9	3	0	0	0	1	3	23	6	2	3	1	4	5	0	27	5	3	4
		Mix wood/fossil	3	0	3	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	1	1	0
		n.i.	4	0	2	0	0	2	0	0	0	0	0	0	1	0	1	0	2	2	1	0	1
8	Energy export from virgin paper included?	Yes	34	23	8	2	0	1	0	0	0	18	3	1	3	1	3	3	2	24	2	2	2
		No	11	5	5	1	0	0	0	0	0	5	2	0	0	0	3	1	0	4	3	1	2
		n.i.	6	0	1	0	0	1	0	1	3	0	2	1	1	0	1	1	0	1	2	1	1
10	Emissions from landfill included?	Yes	43	27	10	1	0	1	0	1	3	23	7	2	3	1	4	3	0	27	5	4	4
		No	8	1	4	2	0	1	0	0	0	0	0	0	1	0	3	2	2	2	2	0	1
11	Energy from incineration substitutes heat?	Yes	42	27	10	1	0	0	0	1	3	23	7	2	2	1	4	3	0	27	5	4	3
		No	6	1	2	2	0	1	0	0	0	0	0	0	2	0	2	2	0	0	1	0	2
		n.i.	3	0	2	0	0	1	0	0	0	0	0	0	0	0	1	0	2	2	1	0	0
12	Energy from incineration substitutes electricity?	Yes	29	14	8	2	0	1	0	1	3	12	4	2	2	1	4	4	0	17	3	2	2
		No	20	14	5	1	0	0	0	0	0	11	3	0	2	0	3	1	0	10	4	2	3
		n.i.	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
13	Alternative use of incineration/landfill capacity included?	Yes	36	18	12	1	0	1	0	1	3	16	6	2	2	1	4	3	2	20	6	4	3
		No	14	10	2	2	0	0	0	0	0	7	1	0	1	0	3	2	0	9	1	0	1
		n.i.	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
14	In which ratio does recycled paper substitute virgin paper?	Data (1:1 or 1:0.8 or 1:0.5 or other)	42	27	10	1	0	0	0	1	3	23	7	2	2	1	4	3	0	27	5	4	3
		n.i.	9	1	4	2	0	2	0	0	0	0	0	0	2	0	3	2	2	2	2	0	2
15	Handling of rejects and de-inking sludge included?	Yes	45	28	13	3	0	1	0	0	0	23	5	1	4	1	7	4	0	26	6	3	5
		No	3	0	1	0	0	1	0	1	0	0	0	0	0	0	0	1	2	2	1	0	0
		n.i.	**3**	0	0	**0**	0	0	**0**	0	3	**0**	2	1	**0**	0	0	**0**	0	1	**0**	1	0

rios analysed

acts				Toxicity								Waste								Wastewater								Land use							
-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i
	-	-		+	+				-	-		+	+				-	-		+	+				-	-		+	+				-	-	
		-		+						-		+						-		+						-		+						-	
0	0	0	0	0	0	0	0	0	0	0	12	5	0	2	0	0	2	0	3	3	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
2	3	1	0	0	0	1	2	0	0	0	31	13	3	5	4	3	3	0	3	6	7	0	0	0	0	0	19	1	1	0	0	0	0	0	1
0	0	0	0	1	0	1	0	0	0	0	3	0	1	0	0	0	1	2	1	0	2	0	2	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	12	5	0	2	0	0	2	0	3	3	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
2	3	1	0	0	0	1	2	0	0	0	33	13	3	5	4	3	4	1	3	6	7	0	1	0	1	0	19	1	1	0	0	0	0	0	1
0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1	3	1	0	0	0	0	0	0	0	0	34	10	2	7	4	3	5	0	3	9	7	0	0	0	0	0	18	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	2	0	0	0	9	8	1	0	0	0	0	0	3	0	0	0	0	0	0	0	10	1	1	0	0	0	0	0	1
0	0	0	0	1	0	1	0	0	0	0	3	0	1	0	0	0	1	2	1	0	2	0	2	0	1	0	0	0	0	0	0	0	0	0	0
0	3	0	0	0	0	0	0	0	0	0	6	0	0	1	0	3	1	0	1	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	0	0	1	2	0	0	0	38	18	3	6	4	0	4	0	6	5	6	0	0	0	0	0	28	1	1	0	0	0	0	0	1
0	0	0	0	1	0	1	0	0	0	0	2	0	1	0	0	0	1	2	0	0	1	0	2	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	1	0	1	0	1	0	0	0	0	35	10	3	7	4	3	5	1	4	9	9	0	1	0	0	0	18	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	2	0	0	0	9	8	1	0	0	0	0	0	3	0	0	0	0	0	0	0	10	1	1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	1	0	1	0	2	2	0	0	0	46	18	4	7	4	3	6	2	7	9	9	0	2	0	1	0	28	1	1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	1	0	1	0	1	2	0	0	0	40	18	3	7	2	3	5	1	5	7	7	0	0	0	0	0	28	1	1	0	0	0	0	0	1
1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	2	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	3	0	1	0	0	0	1	1	1	0	1	0	2	0	1	0	0	0	0	0	0	0	0	0	0
0	3	1	0	0	0	0	0	0	0	0	34	18	3	3	0	3	6	1	0	4	1	0	1	0	1	0	27	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	11	0	0	4	4	0	0	0	3	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	1	0	2	2	0	0	0	1	0	1	0	0	0	0	1	4	0	2	0	1	0	0	0	1	1	1	0	0	0	0	0	1
2	0	1	0	1	0	2	2	0	0	0	38	18	4	6	4	0	4	1	6	5	7	0	1	0	0	0	28	1	1	0	0	0	0	0	1
0	3	0	0	0	0	0	0	0	0	0	8	0	0	1	0	3	2	1	1	4	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0
2	0	1	0	1	0	1	2	0	0	0	38	18	3	6	4	0	4	1	6	5	7	0	0	0	0	0	28	1	1	0	0	0	0	0	1
0	3	0	0	0	0	1	0	0	0	0	5	0	1	1	0	3	1	0	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	1	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
1	3	1	0	1	0	2	2	0	0	0	24	11	3	2	0	3	5	1	4	4	3	0	1	0	0	0	19	1	1	0	0	0	0	0	1
1	0	0	0	0	0	0	0	0	0	0	20	7	1	5	4	0	0	0	3	5	6	0	0	0	0	0	9	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
2	0	1	0	1	0	1	2	0	0	0	32	14	2	6	4	0	1	2	7	5	8	0	1	0	1	0	19	1	1	0	0	0	0	0	1
0	3	0	0	0	0	0	0	0	0	0	14	4	1	1	0	3	5	0	0	4	1	0	0	0	0	0	9	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	1	0	1	0	1	2	0	0	0	38	18	3	6	4	0	4	1	6	5	7	0	0	0	0	0	28	1	1	0	0	0	0	0	1
0	3	0	0	0	0	1	0	0	0	0	8	0	1	1	0	3	2	1	1	4	2	0	2	0	1	0	0	0	0	0	0	0	0	0	0
1	3	1	0	0	0	1	0	0	0	0	44	18	4	7	4	3	5	0	4	9	8	0	1	0	0	0	27	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	1	2	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
1	0	0	**0**	0	0	**1**	2	0	**0**	0	0	**0**	0	0	**0**	0	0	**0**	3	0	**0**	0	0	0	**0**	0	0	**1**	1	1	**0**	0	0	**0**	**0**	**1**

Table A5.3 Distribution of results of the environmental impact of recycling versus incineration — excludi

Code	System boundary conditions		Number of scenarios	Energy								Resource consumption								Energy related impa			
				+++	++	+	0	-	--	---	n.i	+++	++	+	0	-	--	---	n.i	+++	++	+	0
1	Alternative use of land/wood included?	Yes	3	1	2	0	0	0	0	0	0	1	2	0	0	0	0	0	0	1	2	0	0
		No	16	5	5	3	0	0	0	0	3	4	2	1	1	0	5	3	0	4	2	2	3
		n.i.	5	0	2	0	0	2	0	1	0	0	0	0	1	0	1	1	2	2	2	0	1
2	Saved wood used for energy?	Yes	3	1	2	0	0	0	0	0	0	1	2	0	0	0	0	0	0	1	2	0	0
		No	18	5	6	3	0	1	0	0	3	4	2	1	1	0	5	3	2	6	2	2	3
		n.i.	3	0	1	0	0	1	0	1	0	0	0	0	1	0	1	1	0	0	2	0	1
3	Wood marginal	Wood	16	6	7	3	0	0	0	0	0	5	2	0	1	0	5	3	0	4	4	1	3
		Fossil	3	0	0	0	0	0	0	0	3	0	2	1	0	0	0	0	0	1	0	1	0
		n.i.	5	0	2	0	0	2	0	1	0	0	0	0	1	0	1	1	2	2	2	0	1
4	Virgin paper	Wood	6	1	3	2	0	0	0	0	0	0	0	0	1	0	3	2	0	0	2	0	1
	- Electricity marginal	Fossil	14	5	5	1	0	0	0	0	3	5	4	1	0	0	3	1	0	5	3	2	2
		Mix wood/fossil	4	0	1	0	0	2	0	1	0	0	0	0	1	0	0	1	2	2	1	0	1
		n.i.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Virgin paper	Wood	19	6	8	3	0	1	0	1	0	5	2	0	2	0	6	4	0	4	6	1	4
	- Steam marginal	Fossil	3	0	0	0	0	0	0	0	3	0	2	1	0	0	0	0	0	1	0	1	0
		n.i.	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
6	Recovered paper	Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	- Electricity marginal	Fossil	24	6	9	3	0	2	0	1	3	5	4	1	2	0	6	4	2	7	6	2	4
		n.i.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Recovered paper - Steam marginal	Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	- Steam marginal	Fossil	17	6	4	3	0	0	0	1	3	5	3	1	1	0	3	4	0	5	4	1	3
		Mix wood/fossil	3	0	3	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	1	1	0
		n.i.	4	0	2	0	0	2	0	0	0	0	0	0	1	0	1	0	2	2	1	0	1
8	Energy export from virgin paper included?	Yes	7	1	3	2	0	1	0	0	0	0	0	0	1	0	2	2	2	2	1	0	1
		No	11	5	5	1	0	0	0	0	0	5	2	0	0	0	3	1	0	4	3	1	2
		n.i.	6	0	1	0	0	1	0	1	3	0	2	1	1	0	1	1	0	1	2	1	1
10	Emissions from landfill included?	Yes	16	5	5	1	0	1	0	1	3	5	4	1	1	0	3	2	0	5	4	2	3
		No	8	1	4	2	0	1	0	0	0	0	0	0	1	0	3	2	2	2	2	0	1
11	Energy from incineration substitutes heat?	Yes	15	5	5	1	0	0	0	1	3	5	4	1	0	0	3	2	0	5	4	2	2
		No	6	1	2	2	0	1	0	0	0	0	0	0	2	0	2	2	0	0	1	0	2
		n.i.	3	0	2	0	0	1	0	0	0	0	0	0	0	0	1	0	2	2	1	0	0
12	Energy from incineration substitutes electricity?	Yes	11	1	3	2	0	1	0	1	3	0	2	1	2	0	3	3	0	1	3	1	2
		No	11	5	5	1	0	0	0	0	0	5	2	0	0	0	3	1	0	4	3	1	2
		n.i.	2	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	2	2	0	0	0
13	Alternative use of incineration/landfill capacity included?	Yes	18	5	7	1	0	1	0	1	3	5	4	1	0	0	4	2	2	7	5	2	2
		No	5	1	2	2	0	0	0	0	0	0	0	0	1	0	2	2	0	0	1	0	1
		n.i.	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1
14	In which ratio does recycled paper substitute virgin paper?	Data (1:1 or 1:0.8 or 1:0.5 or other)	15	5	5	1	0	0	0	1	3	5	4	1	0	0	3	2	0	5	4	2	2
		n.i.	9	1	4	2	0	2	0	0	0	0	0	0	2	0	3	2	2	2	2	0	2
15	Handling of rejects and de-inking sludge included?	Yes	18	6	8	3	0	1	0	0	0	5	2	0	2	0	6	3	0	4	5	1	4
		No	3	0	1	0	0	1	0	1	0	0	0	0	0	0	0	1	2	2	1	0	0
		n.i.	3	0	0	0	0	0	0	0	3	0	2	1	0	0	0	0	0	1	0	1	0

ng Study S9 (24 scenarios analysed)

acts				Toxicity								Waste								Wastewater								Land use							
-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i
	-	-		+	+				-	-		+	+				-	-		+	+				-	-		+	+				-	-	
		-		+						-		+						-		+						-		+						-	
0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	0	0	0	0	1	2	0	0	0	13	0	0	5	4	3	1	0	3	6	7	0	0	0	0	0	1	1	1	0	0	0	0	0	1
0	0	0	0	1	0	1	0	0	0	0	3	0	1	0	0	0	1	2	1	0	2	0	2	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	3	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	0	0	0	0	1	2	0	0	0	15	0	0	5	4	3	2	1	3	6	7	0	1	0	1	0	1	1	1	0	0	0	0	0	1
0	0	0	0	1	0	1	0	0	0	0	1	0	1	0	0	0	0	1	1	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1	3	0	0	0	0	0	0	0	0	0	16	0	0	5	4	3	1	0	3	9	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1
0	0	0	0	1	0	1	0	0	0	0	3	0	1	0	0	0	1	2	1	0	2	0	2	0	1	0	0	0	0	0	0	0	0	0	0
0	3	0	0	0	0	0	0	0	0	0	6	0	0	1	0	3	1	0	1	4	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	1	2	0	0	0	11	0	0	4	4	0	0	0	6	5	6	0	0	0	0	0	1	1	1	0	0	0	0	0	1
0	0	0	0	1	0	1	0	0	0	0	2	0	1	0	0	0	1	2	0	0	1	0	2	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	0	0	1	0	1	0	0	0	0	17	0	1	5	4	3	1	1	4	9	9	0	1	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	3	0	0	1	0	2	2	0	0	0	19	0	1	5	4	3	2	2	7	9	9	0	2	0	1	0	1	1	1	0	0	0	0	0	1
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	3	0	0	1	0	1	2	0	0	0	13	0	0	5	2	3	1	1	5	7	7	0	0	0	0	0	1	1	1	0	0	0	0	0	1
1	0	0	0	0	0	0	0	0	0	0	3	0	0	0	2	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	3	0	1	0	0	0	1	1	1	0	1	0	2	0	1	0	0	0	0	0	0	0	0	0	0
0	3	0	0	0	0	0	0	0	0	0	7	0	0	1	0	3	2	1	0	4	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	0	0	0	0	0	11	0	0	4	4	0	0	0	3	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	1	0	2	2	0	0	0	1	0	1	0	0	0	0	1	4	0	2	0	1	0	0	0	1	1	1	0	0	0	0	0	1
2	0	0	0	1	0	2	2	0	0	0	11	0	1	4	4	0	0	1	6	5	7	0	1	0	0	0	1	1	1	0	0	0	0	0	1
0	3	0	0	0	0	0	0	0	0	0	8	0	0	1	0	3	2	1	1	4	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	1	2	0	0	0	11	0	0	4	4	0	0	1	6	5	7	0	0	0	0	0	1	1	1	0	0	0	0	0	1
0	3	0	0	0	0	1	0	0	0	0	5	0	1	1	0	3	1	0	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	1	1	1	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
1	3	0	0	1	0	2	2	0	0	0	6	0	1	1	0	3	1	1	4	4	3	0	1	0	0	0	1	1	1	0	0	0	0	0	1
1	0	0	0	0	0	0	0	0	0	0	11	0	0	4	4	0	0	0	3	5	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	1	2	0	0	0	14	0	0	4	4	0	1	2	7	5	8	0	1	0	1	0	1	1	1	0	0	0	0	0	1
0	3	0	0	0	0	0	0	0	0	0	5	0	0	1	0	3	1	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	1	0	1	2	0	0	0	11	0	0	4	4	0	0	1	6	5	7	0	0	0	0	0	1	1	1	0	0	0	0	0	1
0	3	0	0	0	0	1	0	0	0	0	8	0	1	1	0	3	2	1	1	4	2	0	2	0	1	0	0	0	0	0	0	0	0	0	0
1	3	0	0	0	0	1	0	0	0	0	17	0	1	5	4	3	1	0	4	9	8	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	0	0	0	0	0	2	0	0	0	0	0	1	2	0	0	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0
1	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	1	1	1	0	0	0	0	0	1

Table A5.4 Distribution of results of the environmental impact of recycling versus landfilling, 19 scenario

Code	System boundary conditions		Number of scenarios	Energy								Resource consumption								Energy related impa			
				+++	++	+	0	-	--	---	n.i	+++	++	+	0	-	--	---	n.i	+++	++	+	0
1	Alternative use of land/wood included?	Yes	13	7	4	2	0	0	0	0	0	1	2	1	1	3	1	0	4	6	4	1	0
		No	3	3	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	1	0	0
		n.i.	3	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	2	0	2	0	0
2	Saved wood used for energy?	Yes	3	3	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	2	1	0	0
		No	15	7	5	2	1	0	0	0	0	1	2	1	1	3	1	0	6	6	6	1	0
		n.i.	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
3	Wood marginal	Wood	12	8	4	0	0	0	0	0	0	4	2	1	1	3	1	0	0	6	5	1	0
		Fossil	4	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0
		n.i.	3	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	2	0	2	0	0
4	Virgin paper	Wood	5	1	4	0	0	0	0	0	0	0	1	1	1	2	0	0	0	3	2	0	0
	— Electricity marginal	Fossil	11	9	0	2	0	0	0	0	0	4	1	0	0	1	1	0	4	5	3	1	0
		Mix wood/fossil	3	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	2	0	2	0	0
		n.i.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	Virgin paper	Wood	13	8	4	1	0	0	0	0	0	4	2	1	1	3	2	0	0	6	5	1	0
	— Steam marginal	Fossil	4	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	4	2	0	0	0
		n.i.	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0
6	Recovered paper	Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	— Electricity marginal	Fossil	19	10	5	3	1	0	0	0	0	4	2	1	1	3	2	0	6	8	7	1	0
		n.i.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
7	Recovered paper - Steam marginal	Wood	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	— Steam marginal	Fossil	13	7	4	2	0	0	0	0	0	3	2	1	1	2	0	0	4	8	3	0	0
		Mix wood/fossil	3	3	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	0	2	1	0
		n.i.	3	0	1	1	1	0	0	0	0	0	0	0	0	0	1	0	2	0	2	0	0
8	Energy export from virgin paper included?	Yes	7	1	5	0	1	0	0	0	0	0	1	1	1	2	0	0	2	3	4	0	0
		No	7	7	0	0	0	0	0	0	0	4	1	0	0	1	1	0	0	3	3	1	0
		n.i.	5	2	0	3	0	0	0	0	0	0	0	0	0	0	1	0	4	2	0	0	0
10	Emissions from landfill included?	Yes	12	9	0	3	0	0	0	0	0	4	1	0	0	1	2	0	4	5	3	1	0
		No	7	1	5	0	1	0	0	0	0	0	1	1	1	2	0	0	2	3	4	0	0
11	Energy from incineration substitutes heat?	Yes	7	7	0	0	0	0	0	0	0	4	1	0	0	1	1	0	0	3	3	1	0
		No	10	3	4	3	0	0	0	0	0	0	1	1	1	2	1	0	4	5	2	0	0
		n.i.	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0
12	Energy from incineration substitutes electricity?	Yes	6	1	4	1	0	0	0	0	0	0	1	1	1	2	1	0	0	3	2	0	0
		No	11	9	0	2	0	0	0	0	0	4	1	0	0	1	1	0	4	5	3	1	0
		n.i.	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0
13	Alternative use of incineration/landfill capacity included?	Yes	6	2	1	2	1	0	0	0	0	0	0	0	0	0	0	0	6	2	2	0	0
		No	12	8	4	0	0	0	0	0	0	4	2	1	1	3	1	0	0	6	5	1	0
		n.i.	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
14	In which ratio does recycled paper substitute virgin paper?	Data (1:1 or 1:0.8 or 1:0.5 or other)	13	9	1	2	1	0	0	0	0	4	1	0	0	1	1	0	6	5	5	1	0
		n.i.	6	1	4	1	0	0	0	0	0	0	1	1	1	2	1	0	0	3	2	0	0
15	Handling of rejects and de-inking sludge included?	Yes	17	10	4	3	0	0	0	0	0	4	2	1	1	3	2	0	4	8	5	1	0
		No	2	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2	0	0
		n.i.	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

os analysed

acts				Toxicity								Waste								Wastewater								Land use							
-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i	+	+	+	0	-	-	-	n.i
	-	-		+	+				-	-		+	+				-	-		+	+				-	-		+	+				-	-	
		-		+						-		+						-		+						-		+						-	
2	0	0	0	0	0	0	0	0	0	0	13	9	3	1	0	0	0	0	0	6	3	0	0	0	0	0	4	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	2	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	2	1	1	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	3	1	0	0	0	0	0	0	2	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	15	10	4	1	0	0	0	0	0	6	3	1	0	1	0	0	4	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	12	6	3	1	0	0	0	0	2	7	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	2	1	1	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	5	5	0	0	0	0	0	0	0	4	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	11	5	3	1	0	0	0	0	2	3	3	0	0	0	0	0	5	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	2	1	1	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	12	6	3	1	0	1	0	0	2	7	4	0	1	0	0	0	1	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	4	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	1	18	11	4	1	0	1	0	0	2	7	4	1	1	1	0	0	5	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	13	10	2	0	0	0	0	0	1	5	3	0	0	0	0	0	5	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	3	0	1	1	0	0	0	0	1	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	2	1	1	0	0	1	0	0	0	0	0	1	1	1	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	7	1	3	1	0	0	0	0	2	3	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	1	4	4	0	0	0	1	0	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	1	11	5	3	1	0	1	0	0	2	3	3	0	1	0	0	0	5	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	7	6	1	0	0	0	0	0	0	4	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	7	1	3	1	0	0	0	0	2	3	3	0	0	0	0	0	1	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	1	9	9	0	0	0	1	0	0	0	4	1	0	1	0	0	0	4	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	5	5	0	0	0	1	0	0	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	11	5	3	1	0	0	0	0	2	3	3	0	0	0	0	0	5	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	6	5	1	0	0	0	0	0	0	0	0	1	0	1	0	0	4	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	12	6	3	1	0	0	0	0	2	7	4	0	0	0	0	0	1	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	13	6	4	1	0	0	0	0	2	3	3	1	0	1	0	0	5	0	0	0	0	0	0	0	0
0	1	0	0	0	0	0	0	0	0	1	5	5	0	0	0	1	0	0	0	4	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	1	16	10	3	1	0	1	0	0	2	7	4	0	1	0	0	0	5	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	2	1	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Table A5.5 Overview of the distribution of the 15 key system boundary issues in the LCA studies analysed — classified by scenario

Code	System boundary conditions		Number of scenarios	Scenarios taking a given key assumption (%)
1	Alternative use of land/wood included?	Yes	16	22
		No	49	67
		n.i.	8	11
2	Saved wood used for energy?	Yes	16	22
		No	53	73
		n.i.	4	5
3	Wood marginal	Wood	46	63
		Fossil	19	26
		n.i.	8	11
4	Virgin paper — Electricity marginal	Wood	11	15
		Fossil	55	75
		Mix wood/fossil	7	10
		n.i.	0	0
5	— Steam marginal	Wood	50	68
		Fossil	19	26
		n.i.	4	5
6	Recovered paper — Electricity marginal	Wood	0	0
		Fossil	73	100
		n.i.	0	0
7	— Steam marginal	Wood	0	0
		Fossil	60	82
		Mix wood/fossil	6	8
		n.i.	7	10
8	Energy export from virgin paper included?	Yes	41	56
		No	18	25
		n.i.	14	19
9	Main alternative to recycling	Incineration	51	70
		Landfilling	19	26
		30 inc./70 landfill	3	4
10	Emissions from landfill included?	Yes	58	79
		No	15	21
11	Energy from incineration substitutes heat?	Yes	52	71
		No	16	22
		n.i.	5	7
12	Energy from incineration substitutes electricity?	Yes	38	52
		No	31	42
		n.i.	4	5
13	Alternative use of incineration capacity included?	Yes	25	34
		No	46	63
		n.i.	2	3
14	In which ratio does recycled paper substitute virgin paper?	Data indicated (1:1 or 1:0.8 or 1:0.5 or other)	58	79
		n.i.	15	21
15	De-inking sludge considered?	Yes	62	85
		No	5	7
		n.i.	6	8

REVIEW OF COST-BENEFIT ANALYSIS

European Environment Agency

1 Introduction

The cost-benefit analysis study is a follow-up to a review, initiated in October 2003, on existing life cycle assessments (LCAs) for various options for paper recovery and/or disposal. The LCA review analysed the use of LCAs to determine the environmentally best option for disposal or recovery of waste paper. A draft report of this project was delivered in January 2004, and the final report was submitted to the European Environment Agency in April 2004 (Villanueva *et al.*, 2004).

The review of existing LCAs covering alternative recovery and disposal options for paper and cardboard concludes that the overall results of the LCA studies indicate that recycling of waste paper has lower environmental impacts than the alternatives landfilling and incineration. The result is very clear in the comparison of recycling versus landfilling, and less pronounced, but also clear, in the comparison of recycling versus incineration.

Both the LCA and CBA studies are carried out by request from the Environment DG of the European Commission. Their objectives and timing have been agreed on so as to ensure that the outcome could feed into the process towards the thematic strategy on the prevention and recycling of waste. Therefore, the studies take their starting point from the Commission communication COM(2003)301.

The communication is inspired by a life cycle approach to resources management and takes the waste (disposal) stage as its basis. Following this approach, waste prevention and recycling can reduce the environmental impact of resources use in two ways. By:

(1) reducing the use of resources (renewable and non-renewable) and the related environmental impacts;
(2) avoiding negative environmental impacts arising at all stages in the life cycle of a product (cif. life cycle assessment of product systems including services), including extraction and initial processing, transformation and manufacturing, consumption or use and, finally, waste management.

The communication also discusses the potential advantages of setting material-based recycling targets rather than product-based recycling targets. 'Paper' is given as an example of a material to which such logic could be applied. In the communication, the Commission has also made it clear that both life cycle assessment and cost-benefit analysis should be used as a basis for policy-making.

1.1 Objectives

The first objective of the present study is to make a review of existing cost-benefit analysis (CBA) studies covering alternative waste management options for paper and cardboard, such as recycling, incineration with energy recovery, and landfilling. The review is conducted in order to identify whether similarities can be found in the assumptions and conclusions of selected CBA studies on paper and cardboard.

Another objective of the study is to identify and assess the assumptions that have been essential for the conclusions obtained in the studies analysed. These assumptions can be (1) methodological (e. g. scope definition, system boundaries, monetary valuation, discounting, impacts included), or (2) determined by geographical characteristics, economic feedback mechanisms included.

Finally, the aim is to make an overall assessment of the results of the two reviews on LCAs and CBAs, discussing the differences and similarities in assumptions and conclusions.

1.2 Approach and methodology

Contrary to the ISO 14040–14043 standards for LCAs (ISO, 1997; 1998; 2000a and 2000b), there are no international standards for conducting CBAs and as a result, many different assumptions and guidelines have been applied in the CBA studies reviewed. To take account of this problem, the review includes a brief review of selected European guidelines on cost-benefit analyses and impact assessments. Four guidelines have been examined in order to study if they provide the same recommendations on the approach. The guidelines examined have been prepared by the European Commission, the UK HM Treasury, the Danish Ministry of the Environment, and the OECD.

The review process of CBAs has been carried out as follows:

- a literature search (retrieval);
- a screening of literature from which a limited number of studies were selected for further scrutiny; and finally,
- a comparative assessment of the selected studies.

The present study includes the following activities:

1. preparation of an inventory of existing CBA studies on paper/cardboard, compiling a list of reports and other research materials;
2. description of existing guidelines on conducting a CBA;
3. screening of the studies, based on a number of criteria;
4. selection of studies for a comparative assessment of the methodology, assumptions and conclusions.

Once the CBA and LCA reviews were finalised, a comparison of the conclusions from the review of LCA studies and the review of CBA studies were conducted.

A steering committee has been set up that has commented on earlier versions of the report. The steering committee had the following members:

- Niels Dengsøe, National Environmental Research Institute (NERI) and Aalborg University, Denmark;
- Henrik Wenzel, IPU-Institute for Product Development, Denmark;
- Hans Vos, European Environment Agency;
- Chris Allen, Environment DG.

Niels Dengsøe has provided comments on the approach of the study and contributed to the literature search in his capacity as an expert in cost-benefit analysis on resources and waste management.

Following the introduction to the review in this section, Section 2 gives a short introduction to CBA methodology. The central points of a number of guidelines on CBA are presented in Section 3 with the aim to identify similarities in the guidelines' recommended approach and methodology. An inventory of existing CBA studies is given in Section 4. In Section 5 the framework for assessment of the CBA studies is presented. The results are presented and discussed in Section 6. The conclusion and an outlook are given in Section 7.

2 CBA methodology

The term 'cost-benefit analysis' denotes a methodology the purpose of which is to evaluate whether a specific project is worth implementing for society. The methodology takes as its point of departure welfare economics, which deals with the best possible allocation of (limited) resources in society. CBA is sometimes referred to as 'applied welfare economics'. The optimal allocation is defined as the one that provides the most welfare for society.

'Society' is described as a number of individuals, and it is the individuals' utility that is used as an indicator for the individuals' welfare. This is perhaps the most fundamental assumption in welfare economics. The individuals' utility is the value or benefit that an individual experiences by the consumption of goods. Benefits are defined as increases in human well-being (utility), and costs are defined as reductions in human well-being. Changes in this utility are to be considered as a change in the welfare experienced by the individual. It is furthermore assumed that the individuals' utility can be summed up to represent the welfare of society as a whole.

The value of utility is assumed reflected by the market price. However, some goods are not traded on a market and as a result of that they are not attributed with a market price, such as polluting emissions or the NIMBY ([1]) factor. These goods are often referred to as 'externalities' or 'public goods'. The value of these goods has to be derived in other ways, such as through observed behaviour, surveys, or estimated shadow prices (Boardman *et al.*, 2001).

2.2.1 Arguments for the use of CBA

The argument for using a CBA is that it provides a model of rationality for the assessment of gains and losses from a policy or project initiative. The CBA's insistence on taking into account all gains and losses of 'utility' or 'well-being' means that it — at least in principle — provides a wider view to decision-makers including both private and social costs (compared with financial analysis of private companies or life cycle assessments).

Setting out alternatives for achieving the chosen goal is a fundamental pre-requisite of the CBA. The particular ability of CBA is that it has the capacity to make priorities and to be able to determine the optimal scale of the policy, in other words, where net benefits are maximised. The reason for this ability is that costs and benefits are assigned the same unit. Unlike what is possible with other methods this allows for a comparison of otherwise not comparable consequences.

According to Pearce *et al.* (2004), a properly executed CBA should show costs and benefits according to different social groups of beneficiaries and losers, too.

2.2.2 Arguments against the use of CBA

The methodology has a high level of ambition by, in theory, embracing all significant impacts, including externalities, by ascribing a monetary value to them. Nevertheless, there are numerous reasons why precaution is necessary when interpreting the findings of a CBA. As for many other kinds of decision support tools, the results are dependent on the assumptions applied.

Hanley and Spash (1993) list five problem areas that may arise when applying CBA to environmental issues.

1. Valuation of non-market goods: What valuation methods have been chosen, and how reliable and correct are the monetary value estimates?
2. Ecosystem complexity: How are the effects on the environment (and ecosystem) predicted?
3. Discounting and discount rate: Should discounting be used, and what level of social discount rate should be used?
4. Institutional capture: Is the CBA a truly objective way of making decisions or can institutions capture their own ends?
5. Uncertainty and irreversibility: How are these aspects included in the CBA?

Valuation of non-market goods

Several analyses have been conducted on monetary valuation of non-market goods. As such valuation analyses are rather expensive to conduct, the results of one study are often transferred to other studies

([1]) 'Not in my back yard' refers to local resistance towards locating a landfill in the neighbourhood.

and this is called 'benefit transfer'. However, the valuation of a particular externality is typically related to regional or local conditions, and cannot be transferred without modifications. Moreover, in the absence of new or updated estimates, there may also be a risk of using outdated ones.

Ecosystem complexity

To identify the potential emissions to the environment from a given project, several (LCA) databases are now available. However, to assess the consequences and not only impacts on the environment is still very difficult. In many cases, the best estimate of the environmental externalities relates to categories such as greenhouse gas potential, which neglects the actual consequences (e.g. number of flooded houses due to a sea level rise).

Discounting and discount rate

Discounting is used to weigh the costs and benefits occurring in different periods of time together into a net present value (NPV). Boardman *et al.* (2001) state that discounting reflects the generally accepted idea that a given amount of resources available for use in the future is worth less than the same amount of resources available today. The choice of the real ([2]) social discount rate may have important implications for the outcome of the analysis. This is especially relevant as regards environmental analysis where the benefits, an improved state of the environment, may not occur till after several years.

An example in Jespersen (1994) illustrates the effect of choosing an interest rate of 7 %, 3.5 % and 0 % respectively. Two time horizons are shown; 10 years and 30 years. Using a discount rate of 7 % weights the costs and benefits in 10 years' time by only half of what they are weighted today. If the time horizon is 30 years, the effects in the future are weighted by only 13 % compared with today. Using a discount rate of 0 % implies that costs and benefits taking place in the future, are weighted the same as today.

As described and illustrated in Table 2.1, the choice of discount rate may have a crucial impact on the results of a CBA.

Institutional capture

Regarding the fourth point made by Hanley and Spash (1993), whether the CBA is a truly objective way of making decisions is apparently questionable. In a critical review of CBAs in the literature on municipal solid waste management, Lah (2002) concludes that the approaches chosen in CBAs are often political rather than neutral, and that the research methods are often unclear or unreliable. This conclusion highlights the necessity of transparency in assumptions in CBAs.

Uncertainty and irreversibility

Uncertainty and risks may be difficult to assess or tackle, but the difficulty emphasises the important role for sensitivity analyses and risk analysis to play in a CBA.

Finally, Boardman *et al.* (2001) stress that a good CBA depends on how thorough the analyst is. The CBA has several steps ([3]), and each one is subject to errors. The quality of data is also an important determinant for the outcome of a CBA.

2.2.1. *CBA is a decision support tool*

The role of decision support tools is to supply decision-makers with reliable and objective information. They aim at providing assistance to decision-makers in choosing a course of action, giving all uncertainties surrounding the choice (Walker *et al.*, 2003). However, as CBA in reality rarely comprises all relevant information regarding a given project, either due to data limitations or other practical reasons, it is important to keep in mind that the final choice of a project will typically be a political decision.

Table 2.1 Discount rates and value in the future

	7 %	3.5 %	0 %
10 years	0.51	0.70	1.0
30 years	0.13	0.36	1.0

Source: Jespersen (1994).

([2]) Excluding inflation.
([3]) The six steps suggested in this review are presented in Section 2.6.

A wide spectrum of tools can be used to support decisions on the environmental field. Some of these are environmental impact assessment (EIA), life cycle assessment (LCA), environmental risk assessment (ERA), cost-effectiveness analysis (CEA) and cost-benefit analysis. These methods have different areas of applicability, different advantages, and different disadvantages and their suitability depends on the type of problem that is to be assessed. None of the decision support tools should serve as the sole basis for a decision as they are individually not able to bring forward all relevant aspects of a proposed project.

3 Presentation of four guidelines

Over the years, many textbooks have presented and discussed the theory of cost-benefit analysis. In fact, the CBA as a project or policy assessment methodology dates back more than 100 years (Hanley and Spash, 1993). However, it is only within the last few decades that the methodology has been more widely applied within the environmental field.

According to Pearce *et al.* (2004) 'there have been a number of generally uncorrelated developments in the theory of CBA that, taken together, alter the way in which CBA should be carried out. Interestingly, quite a few of those developments have come from concerns associated with the use of CBA in the context of policies and projects with significant environmental impact'.

Since no international standard exists for the conduct of CBA studies, the aim of this section is, on the one hand, to present similarities and differences in different guidelines and, on the other hand, to serve as a basis for the formulation of quality criteria for the present review.

Three guidelines and an OECD draft report are reviewed with regard to the recommendations made on what to include in a CBA.

- The first guideline, European Commission (2002a–d), is intended for impact assessment of initiatives from the European Commission.
- The second guideline, Møller *et al.* (2000), is a manual on socio-economic analysis from the Danish Ministry of the Environment.
- The third guideline, Treasury (2003), is the UK Green Book on Appraisal and Evaluation in Central Government from the Treasury Office.
- The report, Pearce *et al.* (2004), is a draft document from the OECD concerning state-of-the-art knowledge on central issues in relation to CBA.

In Annex VI, the four guidelines are presented with regard to their recommendations on central issues for the preparation of thorough CBAs.

All four guidelines have been published within the last six years, although the OECD report is still a draft paper. All the guidelines go through the same six basic steps:

(1) formulation of the problem/definition of the project;
(2) description of consequences (scope definition);
(3) monetary valuation;
(4) discounting;
(5) evaluation (net present value (NPV) and conclusion);
(6) evaluation of uncertainty.

However, despite the fact that the overall framework is the same, there are several major differences between the guidelines. Nevertheless, the six steps could be seen as the baseline for what can be called a genuine CBA.

The differences relate primarily to the level of detail by which the guidelines describe how the different phases of a CBA should be preformed. A brief presentation of the differences and similarities is sketched in Table 3.1 and discussed in more detail overleaf.

System delimitation

The general approach seems to be that the system delimitation should follow the population influenced by the impacts. Except for the Commission's guideline, this is in general a national delimitation. However, it is also accepted that large cross-boundary impacts are described.

Nevertheless, typically there is a split between the environmental pressures and the economic effects. On the one hand, transboundary emissions, in other words, substances emitted in the country conducting the CBA but with consequences in other countries, are generally included in a CBA (based on LCA data). On the other hand, the economic effects, such as economic consequences in another country due to transboundary emissions, are generally not included.

With regard to the delimitation in time, there is less guidance. Where the problem is addressed a number of possibilities are presented but no recommendations given.

Methodology for identification of impacts

All the guidelines stress the importance of a systematic approach to identifying impacts.

Table 3.1 Four guidelines on CBA methodology: key issues

	Møller *et al.*	**European Commission**	**HM Treasury**	**Pearce *et al.***
Year of publication	2000	2002 (communication)	2003	2004 (forthcoming)
Geographical scope	Should reflect the affected persons. In general national perspective	Unclear about the geographical delimitation	Accounts for all benefits to the United Kingdom. All impacts on non-UK residents and firms should be identified and quantified separately where reasonable	Follows the scope of the policy. Traditionally, population of a nation. A broader perspective applied where context with international treaty or accepted ethical reason
Methodology for identification of impacts	Table of consequences	A qualified list to consider. Various economic models, approaches to systems analysis, and participatory approaches	N/A	Environmental: LCA, EIA
Procedure for estimating the value of market goods	Calculated market prices to reflect WTP	Market prices (opportunity costs)	Market prices (opportunity costs)	N/A
Procedure for valuation of non-marked goods	The traditional methods ([1]) and avoided cost methods	The traditional methods	The traditional methods	The traditional methods
Inclusion of inflation/ real prices	Yes	Yes	If necessary. Long-term annual deflation target: 2.5 %	Yes
Inclusion of relative price changes	Yes	N/A	Yes, although rarely required	Yes
Adjustment for differences in tax	Yes	Yes	Yes	N/A
Discount rate	3 %	4 %. Long-time horizons lower discount rate	3.5 %. Projects with long-term impacts, more than 30 years: declining discount rate	Declining. No specific recommendation for the rates
Inclusion of 'sunk costs'	Yes	No	No	N/A
Inclusion of distributive effects	Yes To be presented in a separate analysis	Yes To be presented separately	Yes To be presented separately	Yes No clear recommendation for how they should be presented

Note: N/A: No information available. WTP: willingness-to-pay. EIA: Environmental impact assessment.

([1]) The traditional methods are Hedonic pricing methods, travel cost methods, contingent valuation approaches.

However, no specific procedure is recommended except for finding the cause-effect relationships. The OECD report points out that when it comes to environmental impacts, LCA and EIA can be helpful tools for the identification of impacts. The guideline from the European Commission presents and advises on the use of a number of economic models to identify and assess economic consequences and recommends the use of various methods for systems analysis for the identification of externalities.

Procedure for estimating the value of market and non-marked goods

The general recommendation is to use market prices (opportunity costs). The Danish guideline provides comprehensive guidance on how to estimate the prices for various production factors (fixed capital, labour, etc.). When it comes to non-market goods the consistency is high. All guidelines present the same methods. However, the Danish guideline also presents the possibility to apply a value derived through avoided cost estimates. Only the UK study addresses the issue of proscribing a value to saved working and non-working time. However, it is not quite clear whether these values should be applied to transport-related projects only.

Choice of discount rate

The discount rate recommended in the guidelines varies from 3 to 4 %, which is very close. For longer time horizons (i.e. longer than 30 years), two guidelines recommend a declining discount rate. One guideline recommends using a lower discount rate, and one recommends making sensitivity analysis with 1 % and 5 %.

Inclusion of 'sunk costs'

When it comes to 'sunk costs', in other words investments and costs already made, no uniform recommendation is made. Both the European Commission and the UK guideline stress that sunk costs should not be included, whereas the Danish guideline ([4]) argues that society is not bound by previous investments. In other words, it is assumed that all investments are made from scratch.

Inclusion of distributive effects

On the question whether or not to include distributive effects the guidelines are clear: they should be included but in a separate analysis. The OECD report points out that there are different ways of including distributive effects in the CBA itself but gives no recommendation on what method should be preferred. However, reading between the lines the OECD report points out that it is very difficult to make trade-offs between efficiency and equity in a proper way, which is a general problem not yet solved in welfare economics. When it comes to effects on income distribution both the Danish and the European Commission guideline recommend the use of a budgetary analysis.

Sensitivity, risk and transparency

All the guidelines stress the importance of conducting sensitivity analysis and risk assessments. They all have much detail in recommending on methods. They also emphasise the importance of presenting the sensitivity analysis and risk assessment as part of the result. Moreover, it is commonly agreed that the result cannot be presented as an aggregated net present value only, but has to be presented in a transparent and non-aggregated form.

([4]) If the objective is to examine whether society should initiate a new collection scheme for recycling as an alternative to the existing collection for incineration, sunk costs should be accounted for. However, if the objective is to examine the most preferable option, recycling or incineration, sunk costs should not be included. The latter study may have a longer time horizon.

4 Inventory of existing CBA studies

As a second activity in the project, a comprehensive literature search was made in order to identify as many studies on paper and cardboard as possible. The complete list of references categorised according to the five groups below is presented in Annex I: References.

In addition, a large number of people were contacted and asked if they knew of any studies that could be of relevance to the present review. Studies regarded as relevant are cost-benefit analyses or other kinds of economic analyses on recycling, incineration or landfilling of waste paper or waste paper packaging. The list of contacts is found in Annex II.

The studies found have been categorised in five groups:

(1) economic studies on paper, cardboard and packaging;
(2) economic studies on waste;
(3) studies on guidelines and methodology for CBA;
(4) studies on monetary valuation of environmental pressures;
(5) other studies.

The first two groups comprise cost-benefit analyses and other studies including economic assessment of the management of waste paper, cardboard and packaging (of paper and cardboard). The studies that covered either specifically paper/cardboard or several waste streams, but with a separate analysis for paper/cardboard have been included in the first group. The second group includes general studies for waste or municipal waste.

The third group includes studies on guidelines and methodological issues regarding cost-benefit analysis. The fourth group covers methodological issues on monetary valuation of emissions to the environment and environmental impacts.

The last group comprises studies that include economic (or environmental) analyses but are not a genuine CBA. Nevertheless, conclusions may still have relevance for the present review. The reports and scientific articles study various aspects of paper recycling, for example, impacts of fluctuating paper prices, measures implemented to improve recycling such as producer responsibility, and costs of municipal, separate collection schemes, but they cannot be characterised as cost-benefit analyses. These studies are classified in the group 'other' and have not been subject to further review.

The hypothesis from the outset was that many CBAs on paper/cardboard exist. This however, turned out not to be the case. The outcome of the literature search is somewhat surprising, since far fewer studies have been found than expected. Naturally, it cannot be excluded that further studies exist, particularly with national environmental authorities and research institutions.

Among studies on paper and cardboard, only nine CBA-like studies have been found. There are seven studies on paper; one on municipal waste where paper is a separate fraction; and one study is a life cycle assessment where the externalities have been subject to monetary valuation.

Only three studies can be characterised as comprehensive cost-benefit studies. The remaining studies are either scientific articles or less exhaustive reports, that is, of around 20 to 40 pages, which implies that the level of detail is not as high as in a comprehensive report analysing the entire life cycle of paper/cardboard (products) and a number of scenarios.

5 Methodology for the review

In Section 5.1 the methodology is applied to screen the literature for relevant studies, and in Section 5.2 the selected studies and included scenarios are presented. Tables 5.1 and 5.2 give an overview of the selected studies, what they cover and what they conclude.

Section 5.3 presents the criteria applied to review the studies and the exchange rates used to compare the costs in the studies.

5.1 Criteria used to select the CBA studies

On the basis of the guidelines presented in Section 3, a list of screening criteria was identified with the aim to use the set of criteria to select studies of very good quality only. However, if all the criteria were applied strictly, it would almost certainly result in only very few studies being selected for the review.

In the light of the limited number of cost-benefit-like studies on paper and cardboard, as well as the lack of regular policy support studies, a much more pragmatic selection took place.

The three criteria applied in the review relate to the following:

- studies including an economic and environmental assessment of alternative treatment options for waste paper and waste cardboard;
- studies that were transparent regarding assumptions and results achieved;
- studies on paper/cardboard packaging rather than packaging in general;
- studies with a geographical scope within Europe.

It was a central issue for the inclusion of a study that it includes a socio-economic analysis on management of waste paper and not just a financial analysis (for private companies, etc.). The broader perspective and the inclusion of externalities are considered important for the review.

To fulfil the objective of the review, it was crucial that the selected studies have a certain level of transparency. The assumptions made and the choice of scenarios should be clearly described, and it should be evident how the results have been calculated. Preferably, the calculations should be included as well.

The focus of the review is the waste fraction consisting of office paper, printing paper, newspapers, magazines, cardboard, and so on. In comparison, packaging is a more broad category, and in addition to cardboard it includes (laminated) beverage cartons, plastic, metals, and so on. In order help focus on 'paper', studies on packaging have generally been excluded. However, a few studies on paper packaging have been included.

The year of publication could also have been a relevant criterion when selecting studies. It seems reasonable to assume that some, or perhaps even significant, developments in technology have taken place over the last 10 years, which would affect the costs associated with collection, production of new/recycled paper as well as alternative treatment options. Similarly, there may have been a change in consumers' willingness to pay for/accept environmental goods. Such changes are likely to influence the relative prices, and thereby the outcome of a study. In other words, the preferable option 10 years ago might not be the same today. As a result, more recent studies should, in principle, be preferred to older ones in the review. In the present review, however, this was not a real issue in the selection, as the number of relevant studies was limited.

A balanced geographical coverage could also have been a criterion, and preferable, as results could vary from the north to the south of Europe. However, the use of cost-benefit analysis within the area of waste management (and in particular management of paper) does not seem to be that widespread across Europe (Virani and Graham, 1998), so this criterion was not applicable.

5.2 Selected studies

Based on the identified literature and the selection criteria, the nine studies selected for the review are listed below.

S1 — Angst *et al*. (2001) (3 scenarios)
Angst, G., Slark, W., Hutterer, H., Pilz, H., Hutterer, H. (GUA), *Kosten –Nutzen –Analyse*

Verpackungsverwertung (Costs-benefit analysis of packaging), Umweltbundesamt GmbH, Vienna, 2001, (in German).

S2 — Bruvoll (1998) (6 scenarios)
Bruvoll, A. *The costs of alternative policies for paper and plastic waste*, Report 98/2, Statistisk sentralbyrå (Statistical central office), Oslo, 1998.

S3 — Dalager *et al*. (1995) (12 scenarios)
Dalager, S., Drabaek, I., Ottosen, L. M., Busch, N. J., Holmstrand, H. C., Skovgaard, M. and Møller, F., 'Miljøøkonomi for papir- oq papkredsløb. Sammenfatning' (Environmental economics of paper and cardboard circulation. Summary). *Arbejdsrapport fra Miljøstyrelsen*, No 30, Miljøstyrelsen (Danish EPA), 1995d, (in Danish).

S4 — Ekvall and Bäckman (2001) (9 scenarios)
Ekvall, T., and Bäckman, P., *Översiktlig samhällsekonomisk utvärdering av at använda pappersförpackningar* (Outline of socioeconomic evaluation of using paper packaging). CiT Ekologik AB, 2001, (in Swedish).

S5 — Hanley and Slark (1994) (1 scenario)
Hanley, N., and Slark R., 'Cost-benefit analysis of paper recycling: A case study and some general principles', *Journal of Environmental Planning and Management*, Vol. 37, No 2, 1994, pp. 189–197.

S6 — Leach *et al*. (1997) (4 scenarios)
Leach, M. A., Bauen, A. and Lucas N. J. D., 'A systems approach to material flow in sustainable cities — A case study of paper', *Journal of Environmental Planning and Management*, Vol. 40, No 6, 1997, pp. 705–723.

S7 — Petersen and Andersen (2002) (1 scenario)
Petersen, M. L. and Andersen, H. T., *Nyttiggørelse af returpapir — en samfundsøkonomisk analyse (Utilisation of recycled paper — a socioeconomic analysis*), Institut for Miljøvurdering (Environmental Assessment Institute), Copenhagen, 2002 (in Danish).

S8 — Radetzki (1999) (4 scenarios)
Radetzki, M., *Etervinning utan vinning* (Recycling without gaining), ESO-Report Ds 1999:66, Regeringskansliet (Government Offices of Sweden), Stockholm, Sweden, 1999 (in Swedish).

S9 — Craighill and Powell (1996) (1 scenario)
Craighill, A., L. and Powell, J. C., 'Life cycle assessment and economic evaluation of recycling: a case study', *Resources, Conservation and Recycling*, No 17, Elsevier, 1996, pp. 75–96.

Craighill and Powell (1996) is not a traditional cost-benefit analysis, but a life cycle assessment where the environmental pressures have been subject to monetary valuation. Nevertheless, it has been included to illustrate the impacts of the monetary valuation.

The analysis in Angst *et al.* (2001) focuses on the general Austrian waste management rather than paper alone, but it includes a scenario on paper recovery.

The main features of the cost-benefit analyses included in the review are presented in Table 5.1 and 5.2.

All studies include one or more scenarios on recycling, incineration, and landfilling of paper waste. A total of 41 scenarios are included, of which 12 scenarios are from one study (Dalager *et al.*, 1995), and nine scenarios are from Ekvall and Bäckman (2001).

The geographical scope of the studies is mainly countries or regions in northern Europe.

As regards the six basic CBA steps identified in Section 3, most studies include a formulation of the problem, a description of consequences, a monetary evaluation of the consequences, and an evaluation of uncertainty. Very few studies make use of discounting, and five studies have not estimated the net present value of costs and benefits.

The studies' coverage of the life cycle and inclusion of the key system boundary criteria, found in the LCA review (Villanueva *et al.*, 2004), are also shown in Table 5.2. The transportation and waste management stages are clearly the most frequently used, whereas the material extraction is only included in three studies and the manufacturing process in seven. Only four studies include between six and nine of the 15 key criteria from the LCA study. The majority of studies include less than six criteria.

As to the main conclusions, six studies are favourable to recycling, two are favourable to incineration, and two are equally favourable to incineration and landfilling. One study (Ekvall and Bäckman, 2001) calculates the financial cost, the external cost and the value of households' time spent on sorting and transporting paper packaging to collection points. However, the three types of cost are not added into one figure, which is why Table 5.2 is split into three rows, showing that financial cost is favourable to landfill, time cost to landfill and incineration, and external cost to recycling.

Table 5.1 Overview of objective and scope of studies selected

	Study	Objective	Scope			Unit of result
			Scenario(s)	Geographical	Waste fraction	
S1	Angst *et al.* (2001)	Analysis of the specific situation in Austria in 1998 and how paper recovery can be optimised through an 8 % increase in recycling. Further refinement of analysis from a previous CBA published in 1998	• Ref. scenario in 1998 with landfilling • Increased incineration • Increased mechanical-biological treatment	National	Packaging paper, non-packaging paper from households and business	Million ATS/year saved by recycling extra 8 % paper compared with landfill, incineration, and mechanical-biological treatment
S2	Bruvoll (1998)	Analysis of the cost efficiency of the waste hierarchy. The marginal economic and environmental consequences for source reduction (via a tax), recycling, incineration and landfilling	• Tax (1) • Recycling, households and commercial • Incineration, households and commercial • Landfilling, households and commercial	National	Paper from households, paper from commerce	NOK/t of recycling, incineration and landfilling respectively
S3	Dalager *et al.* (1995)	Assessment of whether it is more beneficial for Denmark to recycle or incinerate paper. Includes analysis of increased paper recycling in order to achieve the targets of the Danish waste management plan, 1993–97	• Increased recycling (2) • Increased incineration • Export of waste paper to Sweden	National/ regional	Newspaper, mixed paper, and good quality paper	NPV in DKK of increased recycling, 1991 prices
S4	Ekvall and Bäckman (2001)	Socio-economic assessment of various, existing waste management options for waste paper, collected by the Swedish material recovery company for cardboard	• Recycling (3) • Incineration • Landfilling	National	Separately collected paper and paper packaging from households	SEK/t average tonne of recycling, incineration or landfilling
S5	Hanley and Slark (1994)	Illustration of the applicability of CBA to recycling projects. Case study: paper recycling scheme in Scotland	• Landfill versus recycling	Local — site-specific	Paper in municipal waste	Annual costs in GBP of recycling paper rather than landfilling
S6	Leach *et al.* (1997)	Assessment of whether the waste hierarchy is valid for waste paper	• Externalities high value • Externalities low value • CO_2 neutral • CO_2 counted	Not specific/ national	Waste paper	GBP/t average cost of delivered paper
S7	Petersen and Andersen (2002)	Socio-economic analysis of whether energy recovery of waste paper is a benefit for society	1996–2000 variation in socio-economic benefit by incinerating waste paper	National	Five per cent of the already separately collected paper of lowest grade	Annual socio-economic benefit from increased incineration 1996–2000 in DKK 2000 prices
S8	Radetzki (1999)	Economic analysis of increased recovery compared with other waste management options. Analysis of the Swedish producer responsibility legislation for packaging waste and newspapers	• Recycling of paper packaging • Recycling of newspapers and magazines • Incineration of paper (4) • Landfilling of paper	National	• Used packaging material • Newspapers and magazines • Various paper waste	SEK/t extra managed paper
S9	Craighill and Powell (1996)	Comparison of environmental impacts of recycling compared with landfill. LCA extended with a monetary valuation of externalities	• Avoided landfill due to recycling	Local — site specific	Among others, newspaper and magazines	The GBP/t net benefit externality value of recycling compared with landfill

(1) The tax scenario is not included in this review.

(2) A total of 12 scenarios excluding the baseline.

(3) Three different externality valuation methods for each scenario amounting to at total of nine scenarios.

(4) From the data presented for internal costs of landfilling and incineration, it is evident that they are based on municipal waste and not the recyclable paper fractions.

Table 5.2 Main features of the CBA studies included in the review

	Study	Geographical scope	Six basic CBA steps included? (1)	Life cycle stages 1–5 included? (2)	15 key criteria inclued (from LCA study)? (3)	No of scenarios	Households: time cost included?	Main conclusions			
								Favourable to recycling	Favourable to incineration	Favourable to landfill	Favourable to other (e.g. mechanical-biological treatment)
S1	Angst *et al.* (2001)	Austria	1, 2, 3, 5, 6 unclear with respect to 4	2, 4, 5	8	3	No	Household paper waste and packaging			
S2	Bruvoll (1998)	Norway	1, 2, 3, 5, 6	4, 5	1	6	Yes	Commercial paper waste	Household paper waste		
S3	Dalager *et al.* (1995)	Denmark and Sweden	1, 2, 4, 5, 6	1, 2, 4, 5	11	12	No	Corrugated cardboard (commerce); newspaper and magazines (households); good quality paper (commerce)			
S4	Ekvall and Bäckman (2001)	Sweden	1, 2, 3, 6	2, 4, 5	6	9	Yes	External cost: EPS and ExternE	Time cost External cost: SU method Total cost: SU method	Financial cost Total cost: EPS and ExternE	
S5	Hanley and Slark (1994)	Falkirk, Central Scotland, United Kingdom	1, 2, 3, 5, 6 (4)	4, 5	2	1	No	Household paper waste			
S6	Leach *et al.* (1997)	Sweden and United Kingdom	1, 2, 3, 5, 6	2, 4, 5	5	4	No	If externality cost is low	If externality cost is high: other waste management options		
S7	Petersen and Andersen (2002)	Denmark	1, 2, 3, 5, 6	5	2	1	No		Low quality paper: When waste paper price relatively low		
S8	Radetzki (1999)	Sweden	1, 2, 3, 5	2, 4, 5	None	4	Yes		Household paper waste Packaging		
S9	Craighill and Powell (1996)	Milton Keynes, United Kingdom	1, 2, 3	2, 4, 5	1	1	No	External cost only			

(1) 1. Formulation of the problem. 2. Description of consequences. 3. Monetary valuation. 4. Discounting. 5. Evaluation (NPV and conclusion). 6. Sensitivity analysis, or inclusion of uncertainty.

(2) 1. Material extraction. 2. Manufacturing. 3. Use. 4. Transportation. 5. Waste management. None of the studies include the third stage, as it is generally accepted that the use stage has little economic or environmental influence in the paper life cycle.

(3) Legend: 1–5 key issues: 1; 6–9 key issues: 2; and 10–14 key issues: 3.

(4) Values are given in annual costs and benefit. The social discount rate is not presented.

Table 5.2 also shows whether the value of households' time spent on sorting and transporting paper to recycling facilities is included in the study.

5.2.1. Scenarios included in the review

A central element of the studies reviewed has been to assess the potential consequences to the environment and society of a given political initiative. An overview of the objective and scope of the studies were presented in Table 5.1.

The review includes a total of 41 scenarios, divided into nine studies. The study by Dalager *et al.* (1995) alone covers 12 scenarios, all without monetary valuation of environmental externalities. The remaining 29 scenarios include monetary valuation of environmental externalities to various degrees, where three studies ([5]) make up approximately two thirds of the scenarios. Annex III lists the 41 scenarios.

The objectives of the studies differ, as some studies compare a number of alternative scenarios with a given baseline scenario (generally the reference situation in a given year), while other studies compare the effects per tonne of waste paper.

Four studies, Angst *et al.* (2001), Dalager *et al.* (1995), Hanley and Slark (1994) and Petersen and Andersen (2002), analyse the effect of changes compared with a baseline situation. In these studies, the scenarios are characterised by increasing or decreasing a certain amount of (paper) waste going to recycling, incineration, landfill or other treatment. The four studies represent 17 scenarios.

Five studies, Bruvoll (1998), Ekvall and Bäckman (2001), Leach *et al.* (1997), Radetzki (1999), and Craighill and Powell (1996), analyse the effect of changes for one tonne of (paper) waste. The five studies represent 24 scenarios.

Table 5.3 Criteria for the review

1.	Objective of analysis: which scenarios are analysed?
2.	Is the system delimitation presented? • Environmental delimitation • Economic delimitation
3.	Has the study gone through the six basic CBA steps? • Formulation of the problem/definition of the project • Description of consequences (scope definition) • Monetary valuation • Discounting • Evaluation (NPV and conclusion) • Evaluation of uncertainty
4.	Which paper life cycle stages are accounted for in the study? • Material extraction • Manufacturing • Use • Transportation • Waste management
5.	Which environmental and economic parameters are included for each stage of the life cycle? • Environmental emissions/impacts • Economic effects: private and social costs
6.	Have the assumptions for estimating the environmental emissions/impact and economic costs been presented in a transparent way?
7.	Are corrections in prices included (e.g. inflation, tax distortions and changes in relative prices)?
8.	What is the discount rate (level, fixed or varying (declining))?
9.	Has a sensitivity analysis been conducted? If so, for which parameters?
10.	Are the distributive consequences presented?

([5]) Ekvall and Bäckman (2001) include nine scenarios, Bruvoll (1998) includes six scenarios, Leach *et al.* (1997), four scenarios.

The waste paper fraction also varies in the studies. In the majority of studies (6) waste paper comprises newspapers, magazines, mixed paper and cardboard; and in three studies (7) waste paper includes both paper and (paper) packaging.

Angst *et al.* (2001) and Bruvoll (1998) include commercial paper, but only Bruvoll (1998) makes a separate analysis. In Angst *et al.* (2001) commercial paper collection is assumed to be optimal already and therefore remains unchanged.

Bruvoll (1998) has calculated the cost for a new and an old landfill. However, only the two scenarios for the new landfill are included in the review. Neither is the tax scenario for source reduction included.

5.3 Criteria used for the review of CBA studies

Based on the four guidelines presented in Section 3, 10 criteria have been identified for the evaluation of the CBA studies. The criteria are presented in Table 5.3.

Originally, a larger set of criteria was developed for the screening of the studies to give an indication of how systematically the studies follow textbook theory for conducting CBAs, and to see how well the studies cover the life cycle of paper. As described in Section 4.1, this proved not to be feasible as only a limited number of studies have been found that analyse the management of waste paper in a socio-economic context. However, as the set of criteria focuses on the central elements of a CBA, they have been transformed and serve as a basis for the analysis of the studies.

The 10 criteria cover three main areas of concern:

- objective of study
- system delimitation
- transparency.

Objective

Criterion 1 states the objective of the study and included scenarios. This information is used to compare the studies relative to their objective and to get an overview of the included scenarios.

System delimitation

Criterion 2 identifies whether a specific system delimitation has been conducted. The focus here is the geographical scope of the economic and the environmental parts of the study. The scope is linked to criterion 4.

Criterion 4 describes the life cycle stages included in the study. Though the focus of the studies is on waste paper, the way waste paper is managed influences the other stages of the paper system from production to disposal (see also Figure 5.1 that illustrates the life cycle of paper). Criterion 4 gives an indication of how many of the processes (8) related to waste paper management are covered by the study. The criterion can also be seen as an indication of how thorough a study has been conducted with respect to assessing the material flow of waste paper.

Criterion 5 identifies the environmental and economic parameters included in each study. To be able to fulfil the objectives of the present review, the environmental and economic parameters are ordered according to the stage in the paper life cycle. The approach allows for comparison of parameters among studies originating from similar stages in the paper life cycle. For instance, the costs for recycling in one study could relate to a recycling plant only, whereas it could also cover collection in another study. Likewise, it is possible to address whether the CO_2 emissions stem from the production, transportation or incineration phases. In Section 6 the parameters are compared in order to assess how much they correlate and to what degree they influence the result of the studies.

Transparency

Criterion 3 serves to identify how complete the studies are compared with the basic structure of a CBA. It is assumed that the closer the studies have followed the usual textbook procedure, represented by the previously presented four guidelines, the more transparent the study is.

Criterion 10 addresses whether the distributive consequences have been covered by the study. In other words, it describes which parties will benefit from either recycling or other treatment of paper.

(6) Bruvoll (1998), Dalager *et al.* (1995), Hanley and Slark (1994), Leach *et al.* (1997), Petersen and Andersen (2002), Radetzki (1999), and Craighill and Powell (1996).
(7) Angst *et al.* (2001), Ekvall and Bäckman (2001), and Radetzki (1999).
(8) A process is, for example, the action of sorting paper, transportation, repulping, or incineration.

Table 5.4 Base year prices used in the studies

	Base year prices	Comments
Angst *et al.* (2001)	N/A	Baseline scenario is 1998
Bruvoll (1998)		Typically 1991, except for direct landfill cost
Dalager *et al.* (1995)	1991	—
Ekvall and Bäckman (2001)	N/A	Various, but mostly 2000 references
Hanley and Slark (1994)	1993	—
Leach *et al.* (1997)	N/A	1993–95 references
Petersen and Andersen (2002)	2000	—
Radetzki (1999)	N/A	Various, several 1997 and 1994 references
Craighill and Powell (1996)	N/A	Only external cost included

Note: N/A denotes that the year prices are presented in is not available.

Criterion 6 concerns to what degree a study is transparent with respect to presenting the assumptions and background data needed to calculate values for the included parameters, which were identified by criterion 5. It is, for example, assumptions regarding number of trucks, transportation distances, collection efficiencies, wages, and so on, needed to calculate the cost of a collection system. It could also be gases assumed to have a climate effect, from where these gases originate, in which amounts they arise, and how these amounts are calculated into a monetary value.

Criterion 7 covers the issue of price corrections. This issue addresses the degree of price comparability. Do the prices used include taxes (non-refundable) or subsidies, and are prices for different years compared? The use of price corrections is important for the sensitivity of the prices used.

Criterion 8 addresses the method and rate of discounting chosen to estimate the net present value. The level of discount rate can, as previously described, be crucial for the result of a study.

Criterion 9 concerns whether a sensitivity analysis is included. If it is conducted, the parameters for the analysis are specified. The result of a CBA usually involves a level of uncertainty, and thus the conclusions based on a CBA will be subject to uncertainty. One reason is the high number of variables assessed in a CBA, the number of assumptions made, and the number of assumptions needed in order to derive numbers to calculate on.

5.3.1. Exchange rates, base year, and so on

Where a comparison of the different economic prices and results across studies is relevant, it has been calculated in euro. The studies cover a range of nine years, and when looking at the sources of data (e.g. monetary valuation of environmental impacts) the range is even wider, perhaps 15 years. For convenience it has been decided not to calculate the prices and results for the same base year, in other words, to discount values to one year.

Table 5.4 shows the base year of the studies, if such a year has been defined. If it has not been defined, the years to which central or the majority of references refer are listed.

In principle, when comparing cost in different countries the cost should be adjusted according to the purchasing power parity (PPP). This way the cost would be presented on equal terms. However, due to the wide year range of studies, no attempt has been made to estimate cost in PPP values. Moreover, the primary aim in this review is to analyse the individual study and the assumptions important for the outcome of the conclusion of that study rather than comparing cost levels of studies.

It has also been decided to use an annual, average exchange rate for the year 2000 in order to calculate the values in euro. The exchange rates are shown in Table 5.5.

Table 5.5 Exchange rates: annual average for 2000

Currency	EUR 1 =
Austrian schilling, ATS	13.76
Pound sterling, GBP	0.61
Danish krone, DKK	7.45
Norwegian krone, NOK	8.11
Swedish krona, SEK	8.45

Source: European Central Bank, and the National Bank of Denmark.

6 Results and discussion

The results of the review of studies are presented and discussed in this section. The section will present how the criteria in Table 5.3 are addressed in each of the nine studies.

First, the objectives and the system delimitations are presented. The purpose is to describe the scope of the studies and their scenarios, and also to illustrate that the studies have been conducted for different purposes. The presentation will show that the system delimitations of the studies are very different, which complicates the comparison of results and assumptions.

Second, the included studies are analysed with respect to how comprehensive they are in the environmental assessment. The analysis relates to the 15 key criteria identified in the LCA review, the coverage of the different life cycle stages and finally, the monetary valuation of externalities.

Third, the economic assumptions are reviewed. The economic assumptions are presented in three groups: financial cost covering the 'conventional' cost elements, other financial cost covering particularities of assumptions, and influence of external cost.

6.1 Review of objectives and system delimitation

6.1.1 Objectives

The objective of each study is presented in Table 5.1 in Section 5.2.

The point of departure in Angst *et al.* (2001), Dalager *et al.* (1995), Hanley and Slark (1994) and Petersen and Andersen (2002) is a scenario analysis of the actual situation for a country or a region at a given time. In comparison, the remaining five studies estimate the costs and benefits per tonne of waste.

Angst *et al.* (2001) and Dalager *et al.* (1995) are conducted as support for political decisions, whereas the other studies are contributions to the debate on recycling and on the waste hierarchy in general.

The majority of the studies have a national scope, Hanley and Slark (1994) and Craighill and Powell (1996) being the exception.

6.1.2 System delimitation

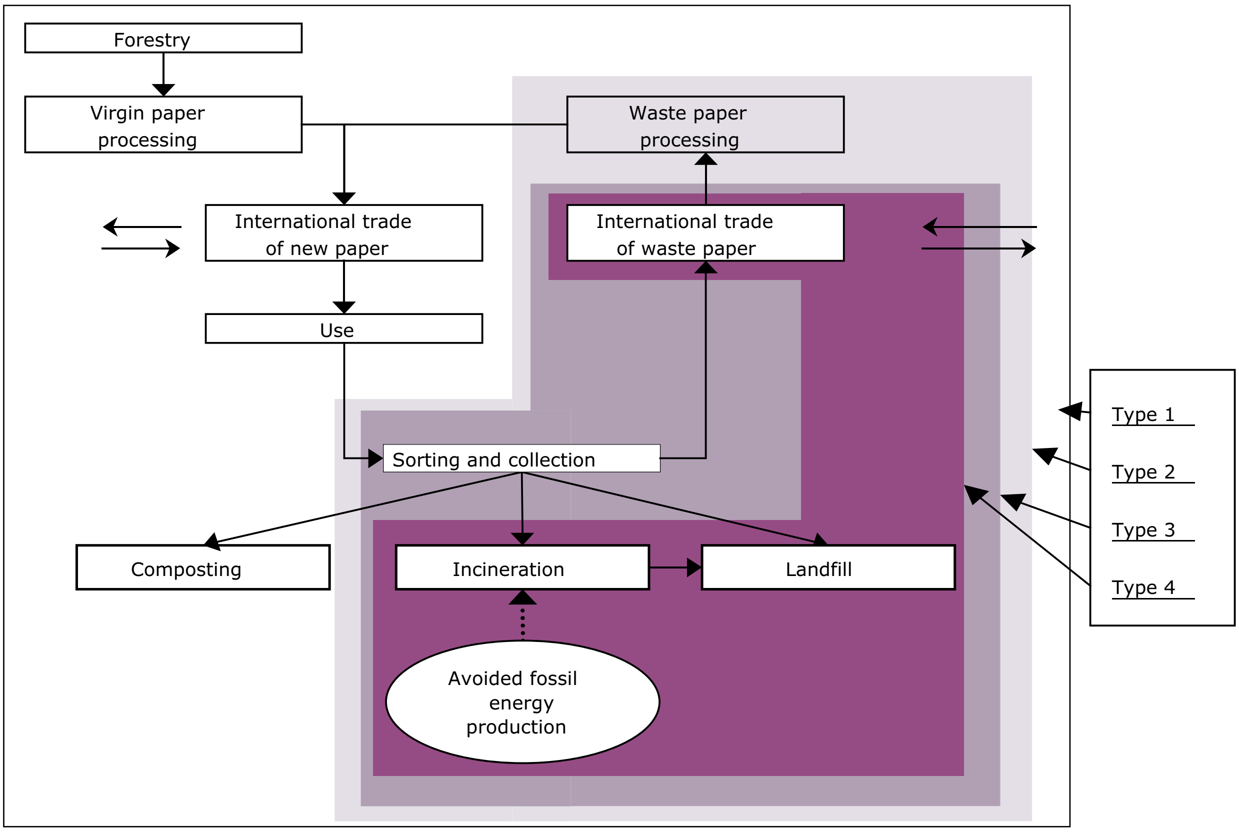
The system delimitations differ from study to study ([9]). Figure 6.1 illustrates this. However, the environmental and economic system delimitation is also different within the individual studies, reflecting an unsystematic systems definition. In some cases the financial costs of collection are included but not the environmental ones. In other cases the financial cost of, for example, repulping paper are included but not the environmental costs or benefits associated with repulping. An example is Dalager *et al.* (1995), who have included the environmental impacts from recycling Danish paper in Sweden but not the economic consequences of this. Another example is Hanley and Slark (1994), who include the economic parameters of collection and recovery but not the environmental parameters connected to these activities. All the studies reviewed are subject to these kinds of inconsistencies.

Another issue that is not always clear is which system delimitation is actually applied. An example is Ekvall and Bäckman (2001), who have used an LCA to derive the environmental parameters that have subsequently been applied a monetary value. However, the system delimitation of this LCA is not presented, and thus it is unclear whether the LCA is concerning, for example, global waste paper management, or whether it has a narrower national scope ([10]). In other cases, a paper management process is included as an avoided production, for example, avoided virgin paper production.

The approach to the system analysis and system delimitation exemplified indicates that the studies

([9]) None of the studies have included the paper use or international trade with virgin paper.
([10]) In connection to combining LCA and CBA there are methodological problems as LCAs are in principle always global in their scope and without time preferences, whereas the CBAs reviewed here are national with a specific time preference.

Figure 6.1 Illustration of the studies' choice of system delimitation



reviewed here generally contain a system analysis, although poorly defined and described.

Figure 6.1 illustrates to what extent the studies have covered the paper cycle identified in the LCA part of the review (Villanueva *et al.*, 2004).

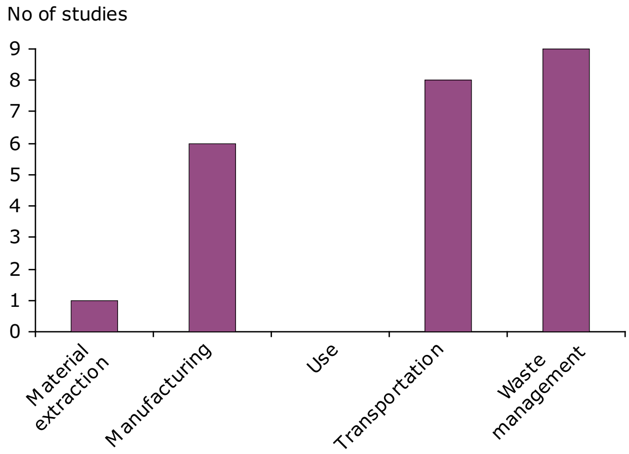
Four main types of system delimitation were identified in the studies.

- Type 1 covers the whole system, indicated by the outer border of Figure 5.1. The studies in this group are; Angst *et al.* (2001), Dalager *et al.* (1995) and Ekvall and Bäckman (2001). However, Ekvall and Bäckman (2001) should have had a slightly narrower system delimitation, as they only discuss the forestry process, but end up not including any primary resource parameters. Their system delimitation begins with the processing of virgin paper. Equally, it seems that Angst *et al.* (2001) are not considering forestry in their system delimitation, however, in their Table 1 they present substitution prices for wood material which seem to be avoidance costs when recovering waste paper, which indicates that they have actually considered raw material extraction. Neither Angst *et al.* (2001) nor Ekvall and Bäckman (2001) consider trade with waste paper reprocessed into new material. Thus, Angst *et al.* (2001) and Ekvall and Bäckman (2001) could have been grouped in a fifth type of system delimitation with a more narrow scope than Dalager *et al.* (1995) and a broader scope than the rest of the studies.
- Type 2 covers a system with the starting point in sorting and collection of waste paper, thus excluding the upstream parameters prior to generation of waste paper. The studies in this group are Leach *et al.* (1997), Radetzki (1999), and Craighill and Powell (1996). Radetzki, however, also includes the external cost of saved virgin paper processing in the analysis, but not the financial cost associated with production of virgin or recycled paper (products).
- Type 3 covers the system with the starting point in waste paper generation, without including the reprocessing of waste paper or making a price for waste paper resemble the reprocessing parameters. The studies in this group are Bruvoll (1998), and Hanley and Slark (1994).
- Type 4 covers the most limited system by including waste management and alternative energy production. The price of waste paper represents the recycling. The study in this group is Petersen and Andersen (2002).

The figure does not take account of whether the system delimitation is for the economic parameters or the environmental parameters. It should be stressed that the figure is a rough indication of how the system delimitations vary for the different studies. For instance, only Angst *et al.* (2001) have included composting of paper as their mechanical-biological treatment scenario and Ekvall and Bäckman (2001) have discussed forestry as a primary resource, although it is not included in the quantitative analysis.

The choice of system boundaries is bound to have an influence on the outcome of a study. The effect of a changed system delimitation is discussed in a 'counter study' by Wenzel (2003) investigating how a different set of system boundaries change the conclusion from Petersen and Andersen (2002).

Figure 6.2 Coverage of the five life cycle stages of paper



From Figure 6.2 describing the studies' coverage of the five life cycle stages, it becomes evident that all studies cover the waste stage of the paper cycle and only one study has regarded the material extraction stage as relevant.

The first stage, material extraction stage (forestry), is covered by only one study: Dalager *et al.* (1995). However, it could be argued that Leach *et al.* (1997) also cover the material extraction stage. They include, in some of their scenarios, a monetary value for CO_2 from biomass based on the argument that paper is not CO_2-neutral if unsustainable forestry takes place due to paper production. Moreover, Ekvall and Bäckman (2001) discuss forestry as a resource.

The second stage, the paper production stage, is included in six out of nine studies. Some of the studies have included the stage as an avoided primary production stage due to recycling, and other studies have both considered virgin and recycled paper production. The three studies that have not considered the production stage, as illustrated in Figure 6.1, are Bruvoll (1998), Hanley and Slark (1994), and Petersen and Andersen (2002).

The third stage of the paper life cycle is the use stage, which is generally not considered to have a financial or environmental ([11]) impact from the paper cycle. None of the studies have considered this stage.

Out of the nine studies, the only study not including the fourth stage, transportation ([12]), is Petersen and Andersen (2002). In connection with this, it should be noted that the choice of collection and transportation system is considered to be an essential financial parameter in some of the studies and the environmental parameter, particles, is equally considered to be an essential parameter in some studies.

The fifth stage, waste management, is clearly covered by all studies as the studies all concern waste management.

6.1.3 Inclusion of CBA steps

The extent to which the studies include the six basic CBA steps is presented in Table 6.1. As can be seen, very few studies discount the result and present it as a net present value. This is interesting as discounting in the theoretical literature is often presented as one of the most important methodological issues for the outcome of a CBA.

6.2 Environmental review

The aim of this section is to describe how thoroughly the studies cover the environmental part of their analysis.

([11]) This is not entirely true as the paper is printed during the use stage, which is closely linked to toxicity and energy consumption.
([12]) In general, from household to landfill or recycling plant.

Table 6.1 Inclusion of the 6 basic CBA steps

CBA steps → Author (year) ↓	Formulation of problem	Description of consequences	Monetary valuation	Discounting	Evaluation	Sensitivity analysis
Angst *et al.* (2001)	X	X	X	(X)	X	X
Bruvoll (1998)	X	X	X		X	X
Dalager *et al.* (1995)	X	X		X	X	X
Ekvall and Bäckman (2001)	X	X	X			X
Hanley and Slark (1994)	X	X	X		X	X
Leach *et al.* (1997)	X	X	X		X	(X)
Petersen and Andersen (2002)	X	X	X		X	X
Radetzki (1999)	X	X	X		X	
Craighill and Powell (1996)	X	X	X	N/A	N/A	N/A

Note: X: included blank: not included N/A: not available.

This section contains four subsections:

- first, a description of how the studies cover the paper material cycle, in other words, how well the studies cover the five life cycle stages of paper ([13]) and the 15 key criteria found to be essential when conducting a LCA for waste paper management;
- secondly, a presentation of the externalities used in the reviewed studies is given;
- thirdly, a comparison of the monetary values applied for the seven most frequently used emission parameters is conducted;
- fourthly, there is a discussion and some concluding remarks concerning the externalities.

Except for Ekvall and Bäckman (2001) and Leach *et al.* (1997) the studies have used fixed monetary unit values for environmental consequences. Ekvall and Bäckman (2001) make use of three scenarios with different monetary unit values and because of that this environmental review section present Ekvall and Bäckman (2001) as S4a, S4b, S4c. Likewise, Leach *et al.* (1997) include two different sets of monetary unit values expressed by study S6a and S6b.

6.2.1 *Coverage of the paper material cycle*

Two approaches have been used to assess to what degree the studies have covered the life cycle of paper material, from felling of trees in forests to final disposal. These are:

- the degree to which the 15 key criteria in the LCA review have been included in the studies;
- the degree to which the studies include parameters from the five stages of the paper cycle.

Table 6.2 The 15 key criteria in the LCA of paper

1.	Is the alternative use of land/wood included?
2.	Is the saved wood used for energy production?
3.	Is wood considered a scarce resource, and what is then the wood marginal?
4.	Which is the marginal energy source for the electricity used in virgin paper production?
5.	Which is the marginal energy source for the heat (steam) used in virgin paper production?
6.	Which is the marginal energy source for the electricity used in recycled paper production?
7.	Which is the marginal energy source for the heat (steam) used in recycled paper production?
8.	Is the energy export from virgin paper production included?
9.	Which is the main alternative to recycling: incineration or landfilling?
10.	Are the emissions from paper landfilling included?
11.	Does the thermal energy produced from incineration substitute other sources?
12.	Does the electricity produced from incineration substitute electricity from the grid?
13.	Are the alternative uses of incineration and landfilling capacity included?
14.	In which ratio does recycled paper substitute virgin paper?
15.	Is the handling of rejects and de-inking waste from paper recovery included?

([13]) 1. material extraction, 2. manufacturing, 3. use, 4. transportation, and 5. waste management stage.

The evaluation of the studies' coverage of the paper cycle has been conducted at study level and not at scenario level. No special attention has been paid to whether the key criteria or life cycle stage is included in the valuation of environmental consequences, economic consequences or both. Thus, it is possible that a study includes a number of life cycle stages in terms of investment costs and operating costs, but only partly includes the external costs associated with the covered life cycle stages.

In the LCA review, 15 key criteria were identified as central for the coverage of the paper life cycle and the subsequent result of the LCA. The 15 key criteria are presented in Table 6.2.

The 15 criteria are ordered from 1 to 15 according to how they match along the life cycle of paper ([14]). Thus, the numbers 6 to 15 relate to recycling and waste disposal, which is equal to the fifth life cycle stage.

Of the 15 criteria, three essential groups should be in focus. They are:

- wood marginal: criteria 2 and 3;
- production energy marginal: criteria 4, 5, 6, and 7;
- incineration marginal: criteria 11, 12, and 13.

Figure 6.3 illustrates the degree to which the studies have included the 15 key criteria. It should be emphasised that it has in many cases proved difficult to identify whether a key criteria has been considered or not. Thus, the result of this evaluation is somewhat uncertain.

The left chart in Figure 6.3 presents the number of key criteria in each study, and the right chart presents the number of studies that include the specific criteria. It should be stressed that the studies may have included more key criteria. It has, however, not been possible to find information on this in the reports.

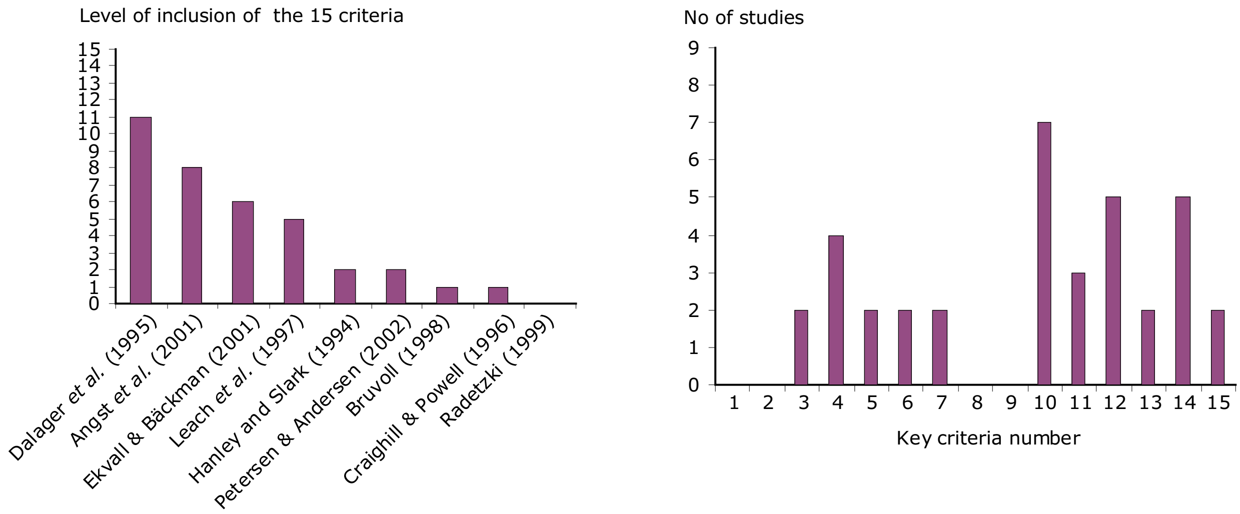
The left chart in the figure indicates that two of the nine studies differ from the rest of the studies by including more than half of the key issues. Five studies have considered two or fewer key criteria.

The right chart in Figure 6.3 illustrates that three issues have been considered by more than half of the studies. They are listed below.

- Criteria No 10, the consideration of emissions from landfill, considered by seven studies;
- Criteria No 14, the substitution ratio of virgin and recycled paper, considered by five studies;
- Criteria No 12, concerning whether electricity produced from incineration substitutes electricity from the grid, considered by five studies.

Criteria No 10 and No 14 are two of the less important of the 15 criteria found in the LCA review. Of the important issues that have been

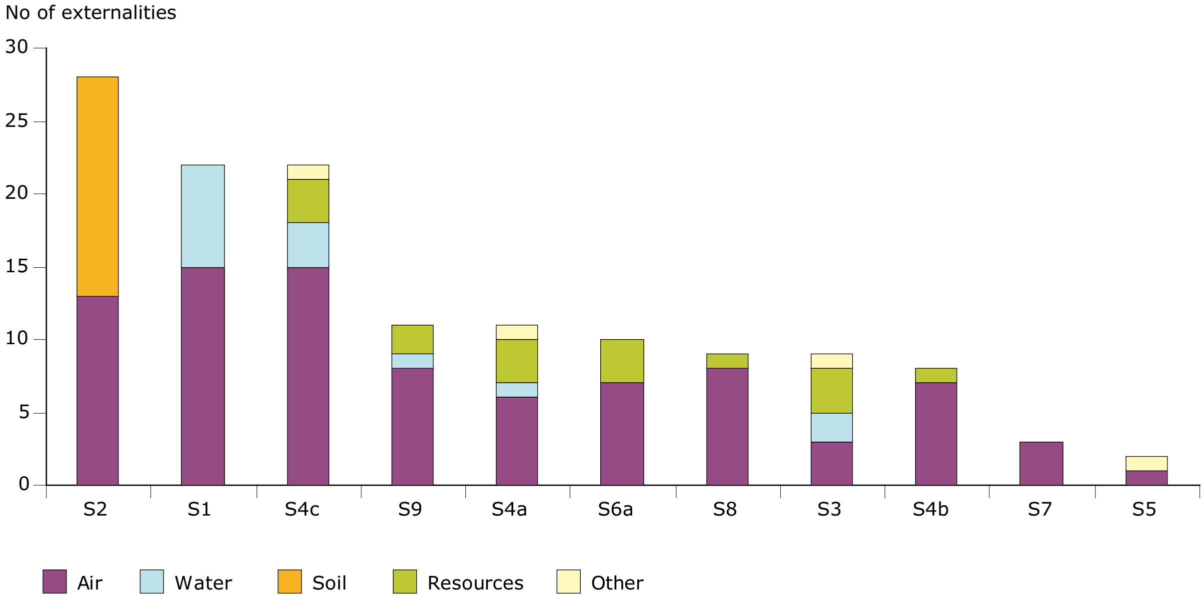
Figure 6.3 Coverage of the 15 LCA key criteria



Note: The background data table can be found in Annex IV, Table 3. Criteria No 9 is not illustrated as it is not an assumption but a question on considered alternatives.

([14]) Except No 15.

Figure 6.4 Total number of externalities included per study



considered are issues No 4 and No 12. They have been considered by four and five studies respectively. Criteria No 4 is concerning marginal energy source for the electricity used in virgin paper production.

Criteria No 1, 2, and 8 have not been included in any of the studies, and the rest of the key criteria have been considered in only two or three studies.

The right chart in Figure 6.3 indicates that only two studies have conducted a system analysis that covers the three essential groups of criteria, the wood marginal (criteria No 2 and 3), production energy marginal (criteria No 4 to 7), and incineration marginal (criteria No 11 and 13). Moreover, the wood marginal is only covered by criteria 3 in the two studies.

6.2.2 *Presentation of externalities*

This section presents the externalities that are included in the nine studies. In some of the studies it is unclear whether a presented externality is actually included in the study or only discussed; in other occasions it is unclear whether the externality is an emission to, for example, air or water.

An example of the lack of transparency is found in Hanley and Slark (1994), who have included a parameter called 'Avoided environmental costs from alternative disposal'. As a proxy for this parameter a sub-parameter is introduced, 'Avoided methane emissions', which consists of possible costs due to explosions and greenhouse gas emissions. However, the estimated value of reduced landfill gas emissions is based on the avoided costs of reducing other sources of greenhouse gases ([15]).

When externality parameters, such as the 'Avoided environmental costs from alternative disposal' used by Hanley and Slark (1994), are introduced in a study it becomes difficult to assess how important the individual parameters are, first of all, it is an aggregated parameter consisting of different sub-parameters. Secondly, it covers a limited amount of externality sub-parameters connected to, in this case, landfills. Thirdly, the derived value for the sub-parameters, in this case methane, is derived from other emissions than methane.

Some of the lack of transparency connected to the values of the externalities can be solved by a thorough systems analysis, for example, in connection to the externality costs connected to landfills, clearly stating which parameters that are present and which that are considered relevant in this study. This would be a systematic approach, improving the transparency of the studies.

([15]) The difference between what is actually valued and what the studies wish to account for is sometimes distant, however, needed in lack of a better proxy.

The following presentation of externalities has been grouped into emissions to air, emissions to soil, emissions to water, resource consumption, and a group of other parameters.

The aim in this section has been to focus on the environmental externalities quantified and included in the individual studies. The only study that presents results in physical quantities and has not applied monetary valuation to externalities is Dalager *et al.* (1995).

Figure 6.4 shows that the number of included externalities varies substantially from Bruvoll (1998) (S2) with 28 parameters, to Hanley and Slark (1994) (S5) with only two parameters included. Six of the nine studies include around 10 parameters, three studies more than 20 parameters and two studies less than five parameters.

Comparing the three most comprehensive studies found from Figure 5.4, could give an indication whether there is a correlation between the number of parameters and the study's coverage of the life cycle, Figure 6.2. The four studies cover 7–22 parameters, and the only correlation found is that studies with less than seven parameters are not in the top four groups.

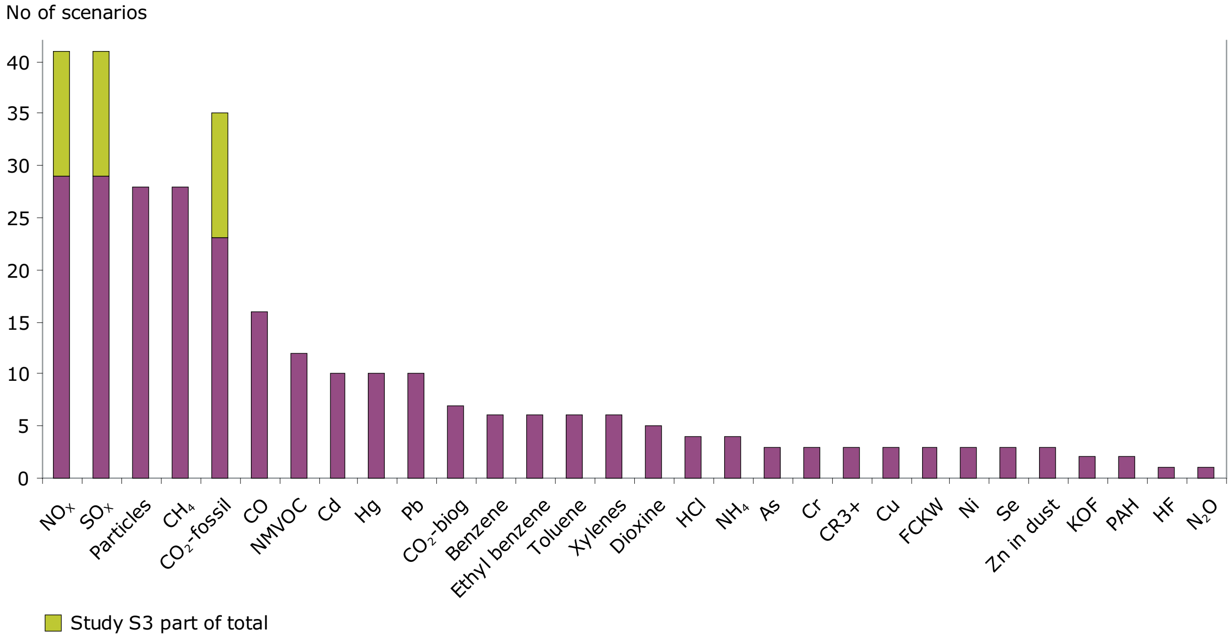
Emissions to air

Most of the externalities ascribed a monetary value are emissions to air and all 41 scenarios have included such emissions.

Figure 6.5 presents the 33 emissions to air by number of scenarios that include the emission. None of the 33 emissions are included in all 41 scenarios; however, the two most applied emissions are SO_x and NO_x that are present in 41 scenarios. When the study by Dalager *et al.* (1995) is excluded ([16]), SO_x and NO_x are present in 29 out of 30 scenarios, and CO_2 fossil is present in 28 scenarios instead of 35.

The first four emission parameters (NO_x, SO_x, CO_2 fossil, and particles) cover more than half the times an air emission is included in the studies, and if CH_4 and CO are included, these six parameters cover 70 % of the times an air emission is considered.

Figure 6.5 Emissions to air related to scenarios including the emission



Note: Study S3 is Dalager *et al.* (1995).

SO_x includes SO_2; CO_2 fossil includes CO_2; Particles include dust, particulate matter, particulates, PM_{10}; CH_4 includes CH_4 (bio) and cost for avoiding CH_4 emission from landfills (which in Hanley and Slark (1994), is assumed to account for

([16]) The reason for excluding Dalager *et al.* (1995) is that they have refrained from applying monetary values to emissions, and part of this exercise is to evaluate to what degree environmental parameters have been included in the economic assessment.

Figure 6.6 Emissions to water by scenarios including the emission

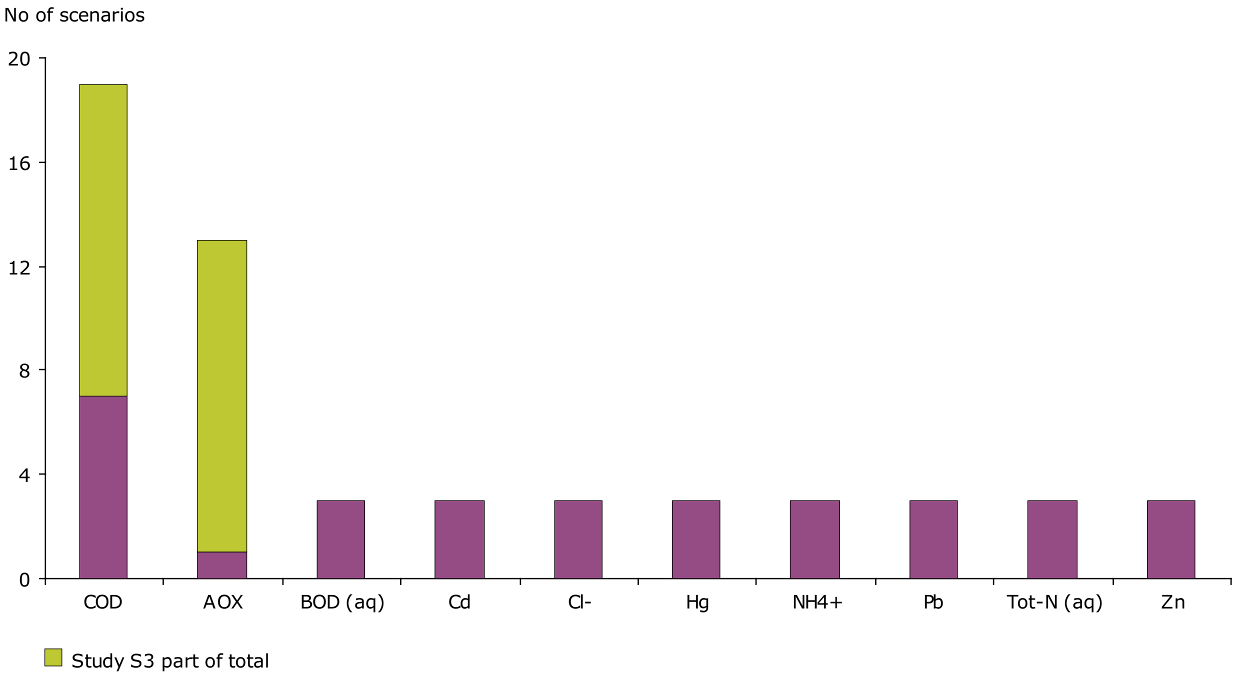
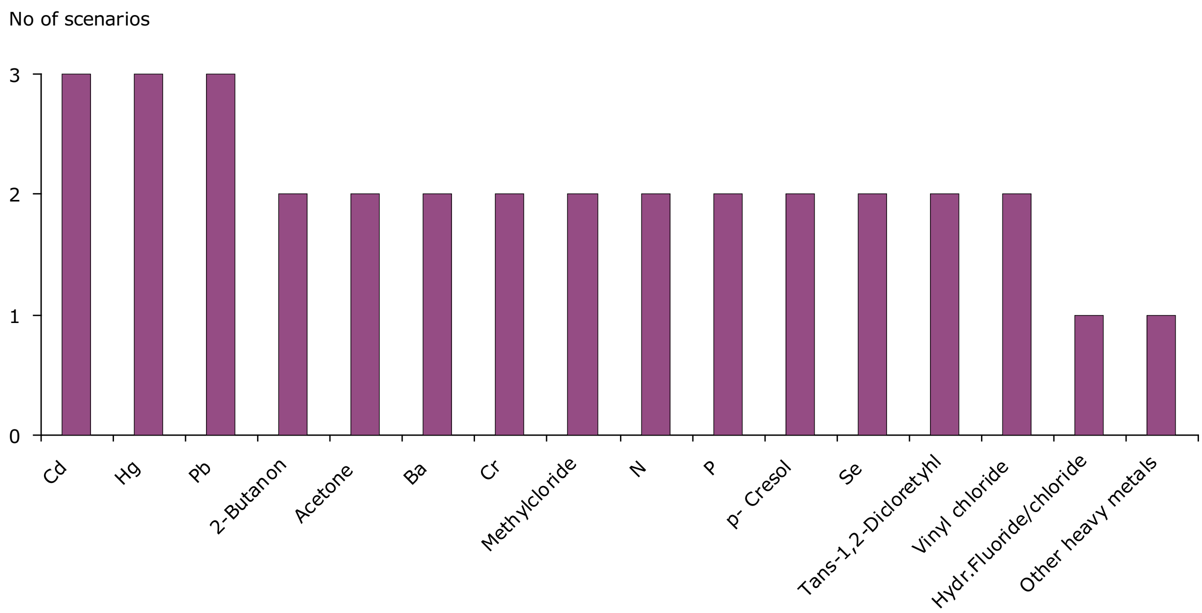


Figure 6.7 Emissions to soil by scenarios including the emission



Emissions to water

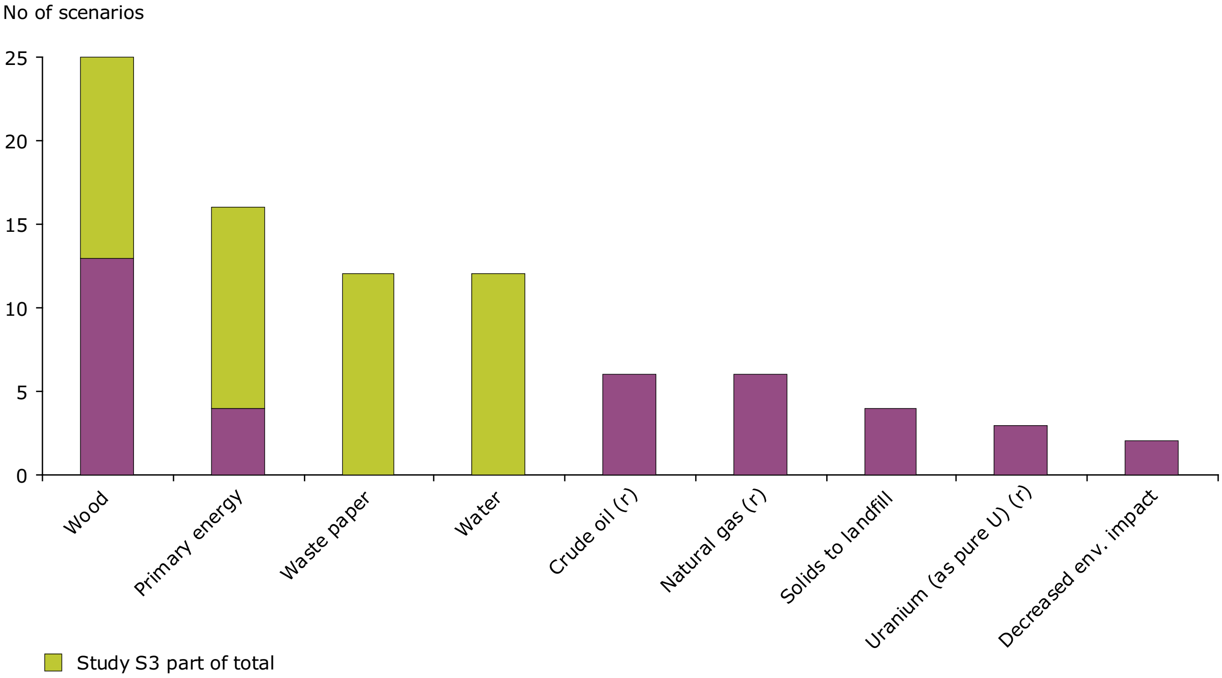
Four studies have included parameters in relation to water. Figure 6.6 presents the 10 parameters by number of scenarios that include the parameter.

When including Dalager *et al.* (1995), the figure shows that 19 scenarios have included COD. However, when excluding Dalager *et al.* (1995), seven scenarios have applied a monetary value to COD, which is equal to three studies ([17]). The rest of the emissions are included in Angst *et al.* (2001) and Ekvall and Bäckman (2001), adding up to seven scenarios considering emissions to water. Of the 10 parameters, eight are present in Ekvall and Bäckman (2001), and the last two parameters are found in one of the two other studies.

Emissions to soil

Figure 6.7 presents the 16 emissions to soil by scenarios including the emission. Only

Figure 6.8 Resource parameters by scenario including the parameter



Bruvoll (1998) has considered emissions to soil. However, it is uncertain if all of the parameters should have been related to soil instead of air or water.

One reason why only one study has included emissions to soil is probably that information is scarce concerning the connection between leaching from landfills and consequences on human health.

Assuming that several of the studies have been inspired by LCAs when finding externality parameters from landfills, another reason could be that traditionally LCAs 'have forgotten' to include the emissions from landfills and instead consider landfills as a final destination.

Resource consumption

Four studies have included externality values for resource consumption in their assessment, covering 25 scenarios ([18]). Excluding Dalager *et al.* (1995), 15 scenarios consider resources in their monetary valuation.

In principle, resources should not be considered in this section about environmental externalities if they posses an expressed market value. Nevertheless, the studies reviewed have chosen to include a number of resource parameters as externalities.

Figure 6.8 presents the resource parameters by number of scenarios that include resource parameters. The figure indicates that when including Dalager *et al.* (1995), there are nine resource parameters. Excluding Dalager *et al.*, (1995), there are seven resource parameters. Of the nine parameters, four can be grouped into one aggregated parameter for energy ([19]).

Leach *et al.* (1997) is the only study that makes use of a parameter indicating resource loss to landfills ([20]), from just landfilling paper. Likewise, Dalager *et al.* (1995) is the only study applying the parameters of water, and waste paper. Lastly, in Radetzki (1999), the only parameter considered not to be an air emission is the parameter 'decreased environmental impact' which is short for: decreased environmental impact from saved production of raw materials. It is unclear whether it is actually a resource parameter or if it is a sum of emissions from raw material production.

Once again these parameters indicate that the studies are not directly comparable as the

([17]) The studies are Ekvall and Bäckman (2001); Craighill and Powell (1996); Angst *et al.* (2001).
([18]) Dalager *et al.* (1995), Ekvall and Bäckman (2001), Leach *et al.* (1997).
([19]) Primary energy, crude oil, natural gas, and uranium.
([20]) By the parameter 'solids to landfill'.

parameters they consider differ and as the system descriptions are weak. In most of the studies it becomes impossible to see whether the varying primary energy parameters are comparable.

Other monetary valued parameters

The group 'other' consists of parameters not fitting into any of the previous four categories. Five studies ([21]) have parameters that are included in this group, adding up to a total of 20 scenarios. When excluding Dalager *et al.* (1995), the total decreases to eight scenarios, where Ekvall and Bäckman (2001) cover the six scenarios.

Figure 6.9 presents five parameters of which only the parameter 'chemicals' from Dalager *et al.* (1995) has not been monetarily valued.

Craighill and Powell (1996) is the only study that considers traffic congestion and transport causalities, even splitting the two parameters into monetary values related to three types of roads and tree levels of seriousness of accidents.

The scarcity value of land is included in Hanley and Slark (1994).

Ekvall and Bäckman (2001) conduct an LCA in order to be able to identify the environmental externalities. The number of parameters found from the LCA is much higher than the number of parameters for which there are monetary unit values. Instead of just leaving out all the parameters lacking a monetary unit value, the parameter 'other (individual contributions < 1 %)' has been introduced, and by conducting a best guess, a monetary value has been applied to all the low external impacts.

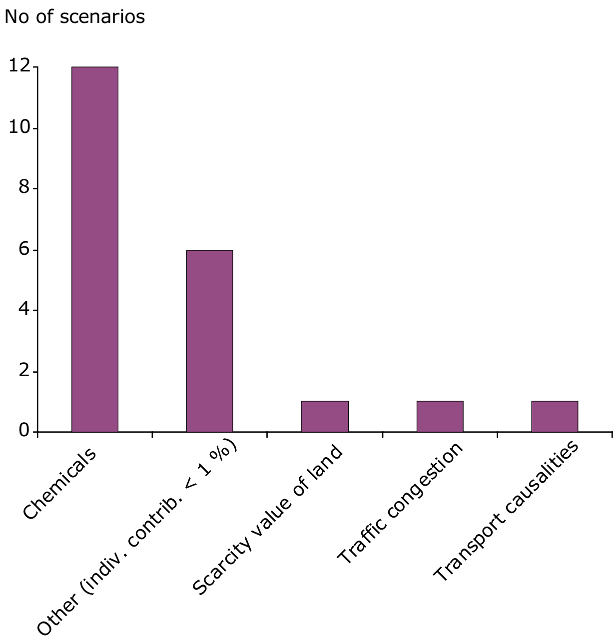
6.2.3 *Monetary value of externalities*

The applied monetary value of externalities varies from study to study. This section attempts to compare the monetary value of the seven most frequently used externalities, which are all emissions to air.

The conversion of monetary values into EUR 2000 prices is explained in Section 5.3.1, and the unit value of the individual studies can be found in Annex III.

Table 6.3 presents the monetary values of the seven externalities. The table reveals that the values vary

Figure 6.9 Other parameters by scenario including the parameter



substantially from study to study. This is analysed further below. Another interesting feature is that the ranking in relation to size of monetary unit value differs among studies. Examples are CO and particles in study S1 and S2. In study S2, particles are the most important parameter and CO the least important parameter, whereas in study S1, particles are the third least important parameter and CO the second least important parameter.

Comparison of ranges in monetary value

The range in value of the seven emission parameters can be seen from the following four charts in Figures 6.10 to 6.13.

Six studies have presented their unit values for CO_2, which are equal to nine different CO_2 values. Ekvall and Bäckman (2001) apply three different valuation methods resulting in the values from S4a (the EPS method), S4b (the ExternE method) and S4c (the SU method). Likewise, Leach *et al.* (1997) have applied a low and a high value represented by S6a and S6b. Figure 6.10 shows that the unit values vary from EUR 3 to 109 per emitted tonne of CO_2, which is a variation by a factor of 40. However, five out of the nine unit values are in the area of EUR 40 per tonne.

([21]) Angst *et al.* (2001), Ekvall and Bäckman (2001), Craighill and Powell (1996), Dalager *et al.* (1995); Hanley and Clark (1994).

Table 6.3 Monetary unit values of the seven most used emissions

EUR-2000 per tonne emission	S2	S1	S4a (1)	S4b (1)	S4c (1)	S9	S6a (2)	S6b (2)	S7	S5	S8	S3
CO_2 fossil	44	63	109	46	47	7	43	3	35	—	N/A	—
CH_4	2 238	2 252	2 738	523	924	118	18 710	2 298	—	5	N/A	—
NO_X	6 041	3 452	2 144	2 161	4 085	2 084	26 916	2 298	4 696	—	N/A	—
Particles	249 018	863	42 627	3 307	3 730	14 738	17 561	2 298	—	—	N/A	—
CO	14	129	—	168	—	10	4 760	2 298	—	—	—	—
NMVOC	1 356	3 452	—	—	14 327	—	—	—	—	—	—	—
SO_X	2 096	4 315	3 291	2 600	6 305	4 241	21 172	2 298	4 025	—	N/A	—

Note: N/A: the study includes the parameter, without stating the value. —: the parameter is not included in the study.

(1) Ekvall and Bäckman (2001) applies three different valuation methods resulting in the values from S4a (the EPS method), S4b (the ExternE method) and S4c (the SU method).

(2) The values for study S6a (high externality values) and S6b (low externality values) have been estimated from Figure 4 in Leach *et al.* (1997). It is not a mistake that the values stay the same for five parameters.

CO is represented by six different values, used in 16 scenarios, which is equal to five studies. The range is from EUR 10 to 4 660 per tonne. The variation is by a factor of 470, which is once again substantial. As seen from Figure 6.10, the values are two by two, within the same order of magnitude.

Of the eight studies that have included CH_4, six studies have presented their values for CH_4. Figure 6.11 shows that the unit values vary substantially for methane from EUR 5 to 18 710 per tonne. In scenario S6a (Leach *et al.*, 1997) it seems as if a VOC value has been chosen to represent CH_4. If this is the case, the VOC value is more in the range of NMVOC in the nine studies than the CH_4 values found. However, refraining from the S6a value still gives a substantial range of a factor of 370, with four of the nine values in the area of EUR 2 400 per tonne.

For comparison, the newest EU values for VOCs affecting rural areas have an EU average of EUR 2 100 per tonne in year 2000 prices. It ranges from EUR 490 per tonne in Finland to EUR 3 000 in Belgium. The EU externality values are further discussed in connection to Table 6.4.

Figure 6.11 shows the three NMVOC values found in three of the nine studies. The values vary from EUR 1 400 to 14 300 per tonne, which is equal to a variation of a factor of 10.

Six studies have presented their values for NO_x, which adds up to the nine values presented in Figure 6.12. The values vary by a factor of 13 from EUR 2 000 to 26 900 per tonne, which is again substantial. If leaving out study S6a, the range is from EUR 2 000 to 6 000 per tonne, with four out of the nine values of around EUR 2 000 per tonne.

Unit values for SO_x are found in six studies with nine different values as presented in Figure 6.12. The values vary from EUR 2 100 to 21 000 per tonne, which is equal to a factor of 10. If study S6a (Leach *et al.*, 1997), is excluded the range is from EUR 2 100 to 6 300 per tonne, which is only a variation by three times the lowest value. Seven out of the nine values are within the range of EUR 2 000 to 4 000 per tonne.

Figure 6.10 Monetary values of CO_2 fossil and CO

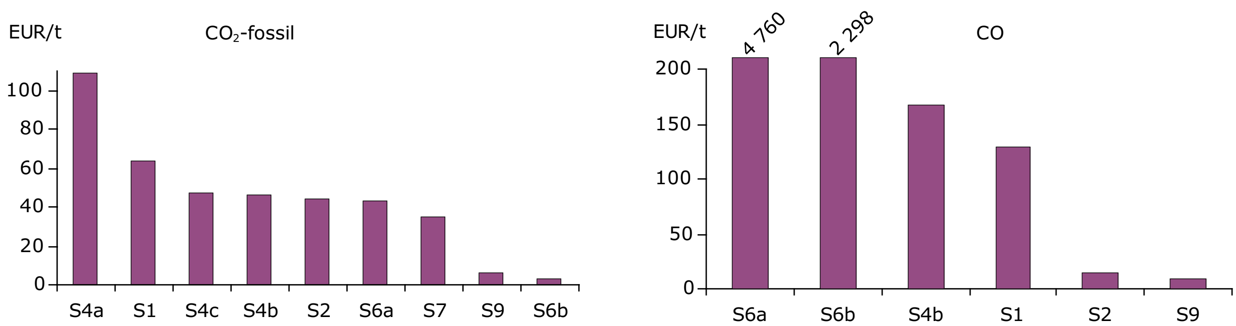


Figure 6.11 Monetary values of CH_4 and NMVOC

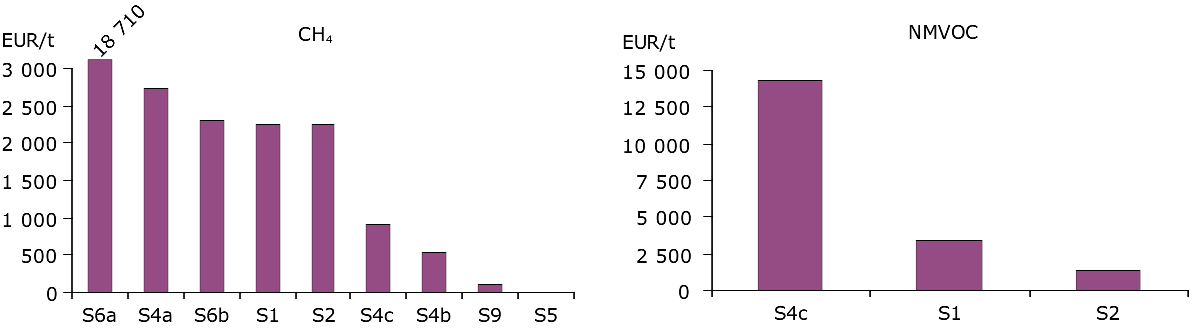
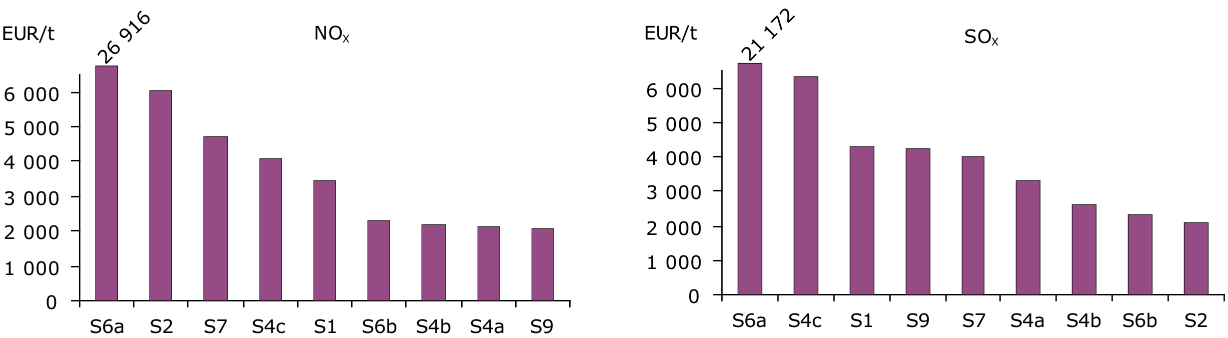


Figure 6.12 Monetary values of NO_x and SO_x



The newest EU average for NO_x is EUR 4 200 per tonne in year 2000 prices. For SO_x it is EUR 5 200 per tonne in year 2000 prices. More detail is shown in Table 6.4.

Values for particles are present in five studies, giving the eight values presented in Figure 6.13. The values vary from EUR 860 to 249 000 per tonne, which is a substantial difference of a factor 290. Three studies have values in the area of EUR 3 500 per tonne ([22]). Only Craighill and Powell (1996) have stated that they valued PM_{10}, for the rest of the studies it is not clear which particle sizes have been applied a monetary value.

The newest EU average for $PM_{2.5}$ is EUR 14 000 per tonne in year 2000 prices. More detail is given in Table 6.4.

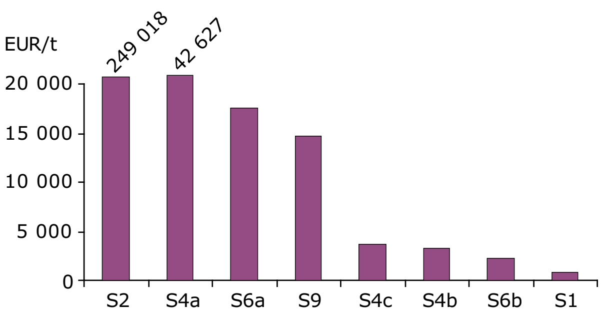
6.2.3 *Concluding remarks*

The number of environmental parameters included in the studies varies from 2 to 28 where half of the studies include around 10 parameters.

All studies have included emissions to air covering a total of 33 different air emission parameters, covering 60 % of the times an externality is considered. The four air emission parameters, NO_X, SO_X, CO_2 fossil, and CH_4, are the most repeated ones. If also particles and CO are included, these six parameters cover 57 % of the cases where air emission is considered in the nine reviewed studies.

For water, 10 different emissions have been considered in three studies. For emissions to soil,

Figure 6.13 Monetary values of particles



([22]) S4b, S4c, and S6b, which are equal to some of the values from Ekvall and Bäckman (2001) and Leach *et al.* (1997).

16 different emissions have been considered in one study only. Various resource parameters, which could be aggregated into five different parameters, have been used in four studies.

Of 'other externalities' four parameters are found from four different studies: scarcity value of land, traffic congestion, traffic causalities and the parameter 'individual contributions < 1 %'.

It can seem surprising that an assessment of what is believed to be relevant environmental consequences from waste management is mainly addressed through air emission parameters. Issues such as resource consumption or disamenity of landfills are rarely addressed, even though these factors are often central for a decision as to whether incineration, landfill or other waste management options are preferable. However, air emissions from energy production are central for all waste management activities, and the seven most frequently applied parameters are thus a good proxy for these activities. Moreover, 10 of the 15 key criteria found in the LCA review are also directly related to energy, and in the LCA review considered to be the most important.

The total monetary valuation for a scenario is important for the conclusion in some of the studies reviewed. All studies that include external costs, make use of monetary unit values derived from other studies, and little attention is paid to conducting a systematic benefit transfer. Often, monetary values seem to be transferred directly and converted into the given currency, perhaps using the purchasing power parity. In this section, it has been illustrated how the monetary values vary considerably from study to study giving reason to conclude that the assumptions behind the monetary values vary considerably.

As stated by Andersen *et al.* (2003), the change in the monetary value over time must be expected, as it reflects the constant scientific development within this field.

An example of how old background data sometimes can be, is the value for CO from the Finansministeriet (2001) (Danish Ministry of Finance).

Table 6.4 Marginal external costs of emissions in rural and urban areas (BeTa), EUR/tonne, 2000 prices

RURAL	SO_2	NO_x	$PM_{2.5}$	VOCs
Austria	7 200	6 800	14 000	1 400
Belgium	7 900	4 700	22 000	3 000
Denmark	3 300	3 300	5 400	7 200
Finland	970	1 500	1 400	490
France	7 400	8 200	15 000	2 000
Germany	6 100	4 100	16 000	2 800
Greece	4 100	6 000	7 800	930
Ireland	2 600	2 800	4 100	1 300
Italy	5 000	7 100	12 000	2 800
Netherlands	7 000	4 000	18 000	2 400
Portugal	3 000	4 100	5 800	1 500
Spain	3 700	4 700	7 900	880
Sweden	1 700	2 600	1 700	680
United Kingdom	4 500	2 600	9 700	1 900
EU-15 average	5 200	4 200	14 000	2 100

URBAN	$PM_{2.5}$	SO_2
City of 100 000 people	33 000	6 000

Population factors	$PM_{2.5}$	SO_2
500 000 people	5	5
1 000 000 people	7.5	7.5
Several million people	15	15

Note: Urban results for NO_x and VOCs are taken to be the same as the rural effects, given that quantified impacts are linked to formation of secondary pollutants in the atmosphere (ozone, nitrate aerosols). Given that these take time to be generated in the atmosphere, local variation in population density has little effect on the results.

Urban externalities for $PM_{2.5}$ and SO_2 for cities of different sizes are calculated by multiplying results for a city of 100 000 people by the factors shown below. Results scale linearly to 500 000 people, but not beyond. These results are independent of the country in which the city is located. Once results for the cities are calculated, nationally specific rural externalities should be added to account for impacts of long-range transport of pollutants (Holland and Watkiss, 2002).

According to Andersen *et al.* (2003), the data refer to a study from 1977 for the medical evaluation of consequences to health from CO, ignoring the rise in knowledge or development of methodology.

Presently, the values of air emissions are heavily based on the mortality factor, giving the choice of methodology for estimating the value of life years lost an essential role for the value of the individual emission parameters.

The uncertainties due to unsystematic benefit transfer, old data, and varying methods for estimating the value of statistical life, seem to be a good explanation of the variations in the monetary values found in this review. Not least if they are combined with the line of assumptions needed to apply an externality cost to, for example, transportation ([23]).

Much work remains in the development of a methodology to estimate monetary values at a European level, if they are to be consistent and comparable among European studies. Presently, the BeTa ([24]) values are the most consistent ones, and the best available monetary values for Danish conditions ([25]) (Andersen *et al.*, 2003). However, BeTa covers only four air emission parameters (see Table 6.4).

If the monetary values of SO_2 ([26]) are compared for the studies with the BeTa values in Table 6.4, the rural BeTa EU average is EUR 5 200/tonne. It is around EUR 1 000/tonne (or more) higher than the values applied in seven out of nine studies, with the extreme being about four times larger than the BeTa average value.

For NO_X, the rural BeTa value is EUR 4 200/ tonne, which is around the same value as used in Petersen and Andersen (2002), and Ekvall and Bäckman (2001) ([27]). Four studies are around half the size, and one study is around six times larger than the BeTa value for rural areas.

If the monetary values of particles are compared for the studies with the BeTa values, it can be seen that Bruvoll (1998) (Norway) has a 146 times higher value than the Swedish average (it is assumed that Sweden and Norway are comparable). Looking at the other extreme, Angst *et al.* (2001) (Austria) uses a value of particles 21 times lower than the lowest monetary value for Austria in BeTa. The EU average for rural areas in the BeTa table is EUR 14 000/tonne, which is about the same value as found in Leach *et al.* (1997) ([28]) and Craighill and Powell (1996).

Conclusion on the environmental parameters

Most of the assumptions governing the importance of external monetary values are not available in the studies.

The number of external parameters included, their size and the completeness of the system delimitation have been compared to the conclusions given in the individual studies. They do not correlate in any way. There is no evidence of a tendency to a higher preference for recycling if more external parameters are included or their values are high. Equally, there are no indications that studies preferring landfill or incineration having fewer externalities included, apply a lower value and a limited system delimitation.

It is other factors that determine to what degree the externalities are important. For instance, Bruvoll (1998) makes use of an extreme value for particles compared with the other studies. However, this value is only important if the amount of emitted particles is large. Such information is not available in the studies. Therefore, it is not possible to state which individual environmental parameters are most influential on the result of a study.

6.3 Economic review

The economic review includes three sub-sections. First, the 'conventional' financial costs included in the studies are presented. Secondly, other cost parameters or assumptions are presented. These may include factors for the calculation of consumer prices, deduction of external costs if emissions are levied by environmental taxes, time and cost spent by households for sorting and collection, and so on. Some of these assumptions may have significant influence on the result. Moreover, the assumptions illustrate the difference between studies, as they are

([23]) Assumptions concerning the emission, transportation pattern, type of vehicle, efficiency, population density, dose–response relationship, and so on.
([24]) BeTa: Benefits table database: Estimates of marginal external costs of air pollution in Europe. Version E1.02a., Holland and Watkiss (2002): http://europa.eu.int/comm/environment/enveco/air/betaec02a.pdf
([25]) The EU value for statistical life is considered too low for Danish conditions (Andersen *et al.*, 2003).
([26]) Assumed here to be equal to SO_x.
([27]) The SU method for valuation of externalities.
([28]) For their high externality value scenario.

typically included in one or two studies only. The last sub-section presents the parameters which seem to be essential for the conclusion of a study.

The social cost-benefit analysis includes two kinds of cost elements: financial cost and external cost. The financial cost is supposed to reflect the actual cost that must be paid for a given political initiative, and the external cost is the monetary valuation of externalities multiplied by the actual emissions. The social cost equals the financial cost plus the external cost.

For the calculation of social cost, the financial cost should not include transfers between individuals in society, nor should it include (non-refundable) taxes and VAT. Thus, adding costs carried by private companies or individuals and the external cost may not equal social cost.

In this section, the presentation is not made scenario-specific, as the economic assumptions typically apply to all the scenarios of a study.

Being a life cycle assessment with inclusion of external cost only, Craighill and Powell (1996) do not include any financial cost in their analysis.

6.3.1 Financial cost

The financial cost includes the usual costs of production of new paper products, and management of (paper) waste. An overview of the financial cost elements is presented in Table 6.5.

Production of products

In Dalager *et al.* (1995), the export price of the final recycled products is an important factor for the result. For example, newspapers are used to produce corrugated cardboard, which is exported at a price of DKK 11 955 per tonne (EUR 1 600).

Collection cost

All studies except Petersen and Andersen (2002) include collection cost in their analyses.

However, in Angst *et al.* (2001) ([29]) an increase in collected quantities of around 8 % is modelled, whereas the specific collection costs (ATS/t) are generally held constant, in other words, marginal cost is nil. It is assumed that the paper-container density is increased and that containers have been moved to more central locations, and so on.

In Radetzki (1999) the net collection cost for newspapers is assumed to be nil, as revenue from sale of paper outweighs the collection cost.

Ekvall and Bäckman (2001) and Radetzki (1999) assume that households cover transport to recycling centres and rinsing of packaging (water, detergents). In Radetzki (1999) households' annual collection cost amounts to a total of SEK 100 per household per year (EUR 12). In Ekvall and Bäckman (2001) the cost of rinsing paper packaging amounts to SEK 67 per tonne, the cost of storing packaging in the home to SEK 128 per tonne, and the transport cost to SEK 70 per tonne.

Sorting and pre-treatment are mentioned in Angst *et al.* (2001), but no explicit cost is associated with the activity.

The type of collection usually determines the collection cost which is considered important for the total cost of a given system. In Table 6.6 below, it can be seen that two of the studies/scenarios favourable to recycling are household-bring schemes (Angst *et al.*, 2001 and Dalager *et al.*, 1995), while the third study is a kerbside collection scheme (Hanley and Slark, 1994).

Unfortunately, it is not possible to make a clear conclusion on whether bring schemes or kerbside collection favour recycling or other means of treatment, as Leach *et al.* (1997) is the only study with a kerbside collection that concludes that other treatment options may be favourable (but only when external cost is high).

Recycling cost

The definition of paper recycling cost varies among the studies. A number of studies do not explicitly describe which activities are included, so it is not fully clear whether the cost covers the same activities. In some cases 'recycling cost' may be net cost, revealed from the sale of waste paper which is assumed deducted from the cost of collecting, sorting, and so on, for example, in Ekvall and Bäckman (2001).

Dalager *et al.* (1995) include the cost of producing recycled paper (products) and the revenue from selling the product. Leach *et al.* (1997) seem to include the cost of producing recycled paper, but it is not possible to follow many of the economic assumptions. Angst *et al.* (2001) include the saved

([29]) The scenario paper 1.

Table 6.5 Financial cost elements

Author (year)	Angst *et al.* (2001)	Bruvoll (1998)	Dalager *et al.* (1995): domestic production	Dalager *et al.* (1995): export of paper waste	Ekvall and Bäckman (2001)	Hanley and Slark (1994)	Leach *et al.* (1997) (6)	Petersen and Andersen (2002)	Radetzki (1999): newspaper	Radetzki (1999): packaging	Craighill and Powell (1996)
Production of products											
Production cost, recycled paper			x				x				N/A
Substituted effects: saved primary production	x								x	x	N/A
Collection											
Collection cost	Nil (1)	x	x	x	x (5)	x	x		Nil (4)	x (4)	N/A
Sorting/Pre-treatment	?	x			x						N/A
Recycling											
Recycling cost	x	x			x						N/A
Sale of waste paper				x	x	x	x	x (3)	x	x	N/A
Sale of recycled product			x								N/A
Landfill											
Landfill cost	x	x	x		x	x	x		x	x	N/A
Incineration											
Incineration cost	x	x	x	x	x		x	x (2)	x	x	N/A
Sale of energy		x	x	x	x		x		x	x	N/A
Substitution of energy	x		x	x				x			N/A

Note: N/A: no information available.?: not certain whether the cost is included or not.

(1) Marginal cost of collecting the extra 8 % is nil.

(2) Investment cost only, as operational cost is assumed counterbalanced by reduced cost for straw-fired burners.

(3) Expresses the value of paper as fuel.

(4) No collection cost is included for newspaper recycling. Collection cost is included for packaging recycling; landfill; and incineration. However, cost for transport, wash and detergents for households are included for both newspapers and packaging.

(5) Cost for transport, wash and detergents for households is included.

(6) See also Table A11 and Figure 7.

production of primary products, wood material and semi-cellulose, in the financial cost.

In Petersen and Andersen (2002), waste paper is assumed to substitute hard coal as fuel for production of energy. Hence, the value of waste paper represents an alternative fuel cost rather than an income.

Landfill and incineration cost

The majority of the studies list a cost of landfill and incineration without giving detailed information on relevant parameters such as the capacity of plant used; kind of technology of plant (state-of-the-art or other), the coverage of cost, and how the cost has been estimated. The cost per tonne for landfill and incineration used in the studies is shown in Table 6.7. The table does not include other waste treatment options, such as mechanical-biological treatment, as this option only appears in Angst *et al.* (2001).

In Ekvall and Bäckman (2001), the collection cost is included in the cost. Radetzki (1999) deducts the revenue from sale of energy from the total cost, thus leaving a net cost figure. Petersen and Andersen (2002) assume that combustion of paper will take place in a rebuilt plant that originally incinerated biomass. The cost includes increased investment cost only, as it is assumed that the operational cost is counterbalanced by a reduction in operational cost of straw-fired burners.

The cost in Angst *et al.* (2001) covers landfill of waste at a landfill for household waste.

Waste paper price

Table 6.8 indicates that the expected revenue per tonne of sold waste paper varies extensively from study to study. Of the nine studies reviewed, five studies have presented the market price they apply for waste paper. The price varies from EUR 6 to 262,

Table 6.6 Type of collection system

Study	Collection system	Source of collection
Angst *et al.* (2001)	Bring scheme	Households
Bruvoll (1998)		
• residential paper	N/A	Households
• commercial paper	N/A	Commerce
Dalager *et al.* (1995)		
• corrugated cardboard	Commerce/collected at site	Commerce
• newspaper and magazines	Bring scheme	Households
• good quality paper	Commerce/collected at site	Commerce
Ekvall and Bäckman (2001)	Bring scheme	Households
Hanley and Slark (1994)	Kerbside collection	Households
Leach *et al.* (1997)	Kerbside collection	Households (1)
Petersen and Andersen (2002)	—	
Radetzki (1999)	Bring scheme	Households
Craighill and Powell (1996)	Kerbside collection	Households

Note: N/A: No information available. —: Collection not included.

(1) Not explicitly mentioned.

Table 6.7 Charges for landfill and incineration, in euro and national currency (1), per tonne

	EUR/tonne		National currency/tonne		National currency
	Landfill	Incineration	Landfill	Incineration	
Angst et al. (2001)	44	94	600	1 300	ATS
Bruvoll (1998)	29	29	235	235	NOK
Dalager et al. (1995)	25	56 (2)	187	419 (2)	DKK
Ekvall and Bäckman (2001)	156 (3)	172 (4)	1 320 (3)	1 450 (4)	SEK
Hanley and Slark (1994)	16	N/A	9.5	N/A	GBP
Leach et al. (1997)	49	90	30	55	GBP
Radetzki (1999)	59	36 (5)	500	300 (5)	SEK

(1) The exchange rates in Table 5.5 have been used.

(2) Estimated without net-levy factors and alternative interest rate. Including them would increase the cost to DKK 619 (EUR 83).

(3) Includes collection. The cost calculation is based on a waste charge that comprises: 34 % collection, 17 % treatment, 10 % administration and 8 % investment and maintenance of bins. The remaining 31 % is VAT and landfill tax.

(4) As for (3). In addition, it is assumed that 1 tonne of paper packaging crowds out 1.15 tonnes of regular household waste, thus increasing the price by 10 %.

(5) Net cost: a revenue of SEK 200 from sale of energy is deducted.

which is equal to a difference of about factor 40. Nevertheless, it should be stressed that the prices cover different time periods and different paper fractions.

The market price for paper fluctuates significantly over time as illustrated in Figure 6.14, which complicates the setting of one reliable price. The fluctuating market prices may be the reason for the large variation in prices used in the studies. For newspaper the prices vary from approximately DKK 250 to DKK 1 250 (EUR 33 to EUR 168), which is equal to a difference of five times. For the mixed fraction of lowest value, the variation in price is much higher going from negative values to around DKK 800 (EUR 108).

One study (Petersen and Andersen, 2002) has explicitly based their assessment on a fluctuating market price for waste paper from EUR 6 to 83 for the period 1996 to 2000. In this study, the price of waste paper is crucial for the conclusion. According to the study, it is only socially beneficial to incinerate when the waste paper price is below EUR 54 per tonne (DKK 400 per tonne). From Figure 6.14 it is evident that such a conclusion is highly dependent on the paper fraction and time period investigated.

Hanley and Slark (1994) equally conclude that their result is dependent on the price of waste paper. In their study the waste paper price can go down from GBP 13.67 to GBP 9.04 (EUR 22 to 16) per tonne, before it is no longer profitable for society to recycle paper.

Table 6.8 Variation in waste paper price

Study		Market price of paper National currencies per tonne	Market price of paper EUR per tonne, year 2000 prices
Angst *et al.* (2001)	ATS	1 300 (1)	95
Bruvoll (1998)	NOK	N/A (2)	N/A
Dalager *et al.* (1995)	DKK	275 (3)	37
Ekvall and Bäckman (2001)	SEK	N/A (4)	N/A
Hanley and Slark (1994)	GBP	13.67	22
Leach *et al.* (1997)	GBP	40 to 160 (5)	66 to 262
Petersen and Andersen (2002) 6)	DKK	48 to 616	6 to 83
Radetzki (1999)	SEK	N/A (7)	N/A
Craighill and Powell (1996)	GBP	N/A (8)	N/A

Note: The exchange rates in Table 5.5 have been used.

(1) It is unclear whether the price is for waste paper or pulp.

(2) It is unclear if it is included in the recovery cost or not considered.

(3) Average market price of waste paper independent of grade.

(4) Net cost of recycling based on an average Swedish cost of recycling subtracted the revenue from sale of recovered waste paper.

(5) Varies with the grade. The distribution between the three paper grades is not described.

(6) Price variations for waste paper from 1996–2000.

(7) Net cost of recycling, implying that revenue from sale is subtracted collection costs.

(8) Only external costs.

The assumptions by Radetzki (1999) are that the collection and treatment of packaging for recycling are much more costly than the cost of newspaper, and that the net cost of collection and treatment of newspaper is nil. In addition to lower collection and treatment cost of newspaper, the assumption that net private costs are nil, is supported by the fact that the market value of the waste product is higher.

All in all, two studies conclude that the market price of waste paper is essential to the outcome of the result. In Ekvall and Bäckman (2001), the market price also seems to be a central factor even when the time cost is considered.

6.3.2 *Other financial cost elements included*

In addition to the 'conventional' cost, some authors have included other elements in the calculations. These elements are discussed in this section and presented in Table 6.7.

Time cost

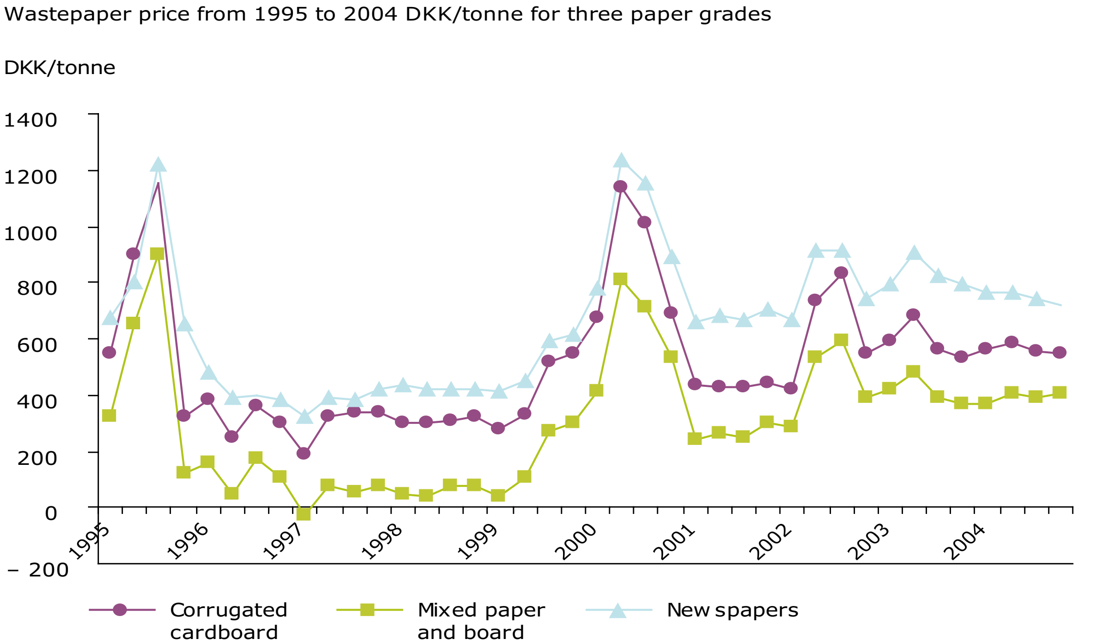
A key issue for the outcome of a study is the inclusion of the value of households' time spent on sorting and transporting recyclable paper and packaging to recycling centres. The so-called 'time cost' is included in Bruvoll (1998), Ekvall and Bäckman (2001), and Radetzki (1999). Bruvoll estimates that 18.9 hours will be spent per tonne of paper, while Ekvall and Bäckman estimate that 25–75 hours (with an average of 50 hours) per tonne of paper packaging are necessary. Radetzki estimates that each household will spend 26 hours per year on this activity. However, Radetzski assumes that the sorting, cleaning and transport of packaging is five times more expensive per tonne than for newspapers.

To estimate the value of households' time, Bruvoll uses a US estimate of NOK 53 per hour, and Radetzki uses an estimate for moonlight work of SEK 60. Ekvall and Bäckman use the same price-estimate as Radetzki, but they include an estimate that leisure time's share is 70–97 % of the 25–75 hours.

In Table 6.10 the effect of time cost on the final result is presented. The official results of the studies that include time cost for recycling, favour landfill and incineration compared with recycling. However, when excluding time cost, recycling becomes more favourable compared to landfill in Ekvall and Bäckman for the EPS and ExternE methods, and more favourable to landfill and incineration in Radetzki. The conclusion in Bruvoll does not change.

There have been discussions on whether or not households' time should be included in the social cost of a political measure. In these discussions it has been argued that household time should be

Figure 6.14 Waste paper price from 1995 to 2004 DKK/tonne for three paper grades



Source: Danish EPA (2004) from *EUWID Recycling & Waste Management*, Volume 8, No 1–25 and Volume 9, No 1.

Note: EUR 1 = DKK 7.45. The market for waste paper is an international market governed by the Asian demand.

included only if they are required by law to sort waste.

Ekvall and Bäckman (2001) also estimate the loss of production in society because households spend time sorting paper packaging, time that could have been spent working and thus earning an income. To estimate the time cost, it was assumed that the leisure time took up 70–97 % of the time spent sorting the paper waste. Thus, the remaining 3–30 % was working time. Based on an average Swedish income, adding a profit of 10 % to the employer and counting only an average share of working time, the loss in production is estimated at SEK 970 (EUR 115), which is added to the time cost. An uncertainty of 50 % is added to the figure.

Radetzki (1999) assumes that companies pay a total of SEK 1.6 million (EUR 190 000) for the additional collection. In total, the collection cost for the 213 000 tonnes of packaging and the 152 000 tonnes of newspaper adds up to SEK 1 627 per tonne (EUR 193 per tonne).

Deduction of environmental taxes

Another interesting assumption relates to the emissions on which environmental taxes are levied, for example, CO_2, NO_x and SO_2. The reasoning is that if environmental taxes are already levied on certain emissions, the value of tax payments should be deducted from the monetary valuation of external effects. The assumption is applied in Ekvall and Bäckman and in Radetzki. Based on the monetary valuation method (the SU method ([30])) and the estimated emissions, Ekvall and Bäckman estimate the tax payments for the three alternatives: recycling, incineration and landfill.

Radetzki takes a pragmatic approach by assuming that the value of the environmental taxes is one third of the external (environmental) cost.

Corrections in prices and other elements

As mentioned in Annex VI.3, the Danish CBA guideline prescribes that prices should reflect the

([30]) The SU method is developed by the University of Stockholm and puts emphasis on emissions of toxic heavy metals (Ekvall and Bäckman, 2001).

Table 6.9 Other financial cost elements included

Author *(year)*	Angst *et al.* (2001)	Bruvoll (1998)	Dalager *et al.* (1995): domestic production	Dalager *et al.* (1995): export of paper waste	Ekvall and Bäckman (2001)	Hanley and Slark (1994)	Leach et al. (1997)	Petersen and Andersen (2002)	Radetzki (1999): newspaper	Radetzki (1999): packaging	Craighill and Powell (1996)
Time cost: households' sorting and collection cost		x			x				x	x	N/A
Time cost: companies' sorting and collection cost									x	x	N/A
Loss in production (due to time spent for sorting and collection)					x						N/A
Deduction in environmental taxes, when including external cost					x				x	x	N/A
Raising producer prices (excluding taxes, etc.) to reflect market prices (including taxes)			x	x							N/A
Inclusion of uncertainty in prices (e.g. incineration and landfill charges)					x						N/A
Alternative interest rate for investment capital			x	x							N/A
Storage of recyclables in households					x						N/A
Risk supplements of landfill	x										N/A

Table 6.10 Time cost per tonne of paper collected, national currency

		Ekvall and Bäckman (2001)			
	Bruvoll (1998)	EPS	ExternE	SU	Radetzki (1999)
National currency	**NOK**	**SEK**	**SEK**	**SEK**	**SEK**
Time cost	1 003 (290–1 716)	2 910 (1) (max. 4 400)	2 910 (1) (max. 4 400)	2 910 (1) (max. 4 400)	6 500 (3)
Total recycling cost, including time cost	2 410	6 069	4 557	8 400	6 426
Total recycling cost, excluding time cost	1 407	3 478	1 966	5 809	– 74
Incineration cost	1 319	5 183 (2)	2 293 (2)	– 69 (2)	1 840
Landfill	2 258	4 925 (2)	2 176 (2)	2 656 (2)	1 842

(1) An average of 50 hours per tonne; 60 SEK/h; 97 % of the time being leisure time. Due to uncertainty, the time cost for recycling is SEK 0 to 4 400, and for incineration/landfilling from SEK 30 to 1 440.

(2) Excluding a time cost of SEK 30 to 1 440 for landfill and incineration.

(3) Newspapers

market prices, which is why the cost in Dalager *et al.* is multiplied by a net levy factor of 1.17 or 1.25, depending on whether the goods are produced domestically or internationally. Dalager *et al.* also applies an alternative interest rate for invested capital as recommended in the guideline.

Ekvall and Bäckman estimate the uncertainty of the prices in the calculation of the direct financial cost. The uncertainty for landfill and incineration is determined to 20 %, and households' transport, time, water, and so on, to 100 %.

In addition to the operating costs, Angst *et al.* (2001) take into consideration that the landfill of waste may constitute a (supplementary) risk that is not reflected in the present market prices. External costs of landfilling are considered in the form of a cost supplement on the landfill prices used. This cost supplement corresponds to the necessity of subsequent clean-up and a partly thermal treatment of the landfill mass. The risk supplement for a landfill for mixed waste is ATS 2 000 (EUR 145) per tonne.

6.3.3 External cost

The estimated external cost of each study is presented in Table 6.11.

The table shows that only the estimated cost in Bruvoll (1998), the ExternE method in Ekvall and Bäckman (2001), and Hanley and Slark (1994) support the waste hierarchy, in other words, external cost for recycling is lower than for incineration, which again is lower than for landfilling. Craighill and Powell (1996) have also estimated lower cost for recycling than for landfilling.

The EPS method in Ekvall and Bäckman (2001) supports recycling as a first priority, landfilling as the second and incineration as the third.

Radetzki (1999) and the SU method in Ekvall and Bäckman (2001) support incineration as the first priority. The second-best option (from the external cost perspective) in Radetzki is recycling, while it is landfill in Ekvall and Bäckman. However, the uncertainty of the SU method is substantial and varies from a possible benefit of SEK 16 000 (EUR 1 970) to a possible cost of SEK 14 500 (EUR 1 790) per tonne.

In Angst *et al.* (2001), the estimated benefit from avoiding landfilling through recycling is ATS 1 731 per tonne, through incineration it is ATS 209 per tonne and through mechanical-biological treatment it is ATS 478 per tonne. Thus, the external costs highly support the result of the study.

The external cost, or rather the avoided external cost, also supports the results in Bruvoll (1998), Hanley and Slark (1994) and Petersen and Andersen (2002). Excluding the external cost in and Petersen and Andersen makes recycling the best option; in Bruvoll incineration will become a better option than landfilling; and in Hanley and Slark landfilling becomes the best option.

6.3.4 Discount rate

Only one study includes the discounting of the six basic CBA steps and estimates the net present value (Dalager *et al.*, 1995). The discount rate used is 3 % in the social CBA and 7 % in the private CBA.

Angst *et al.* (2001) estimates the annuities of investment but the details such as the choice of interest rate seem to be comprised in the model used for the calculations.

6.3.5 Sensitivity analysis

Sensitivity analyses are conducted for the most central parameters in all studies except Radetzki (1999) and Leach *et al.* (1997). However, Leach *et al.* has designed four scenarios with a combination of high and low external cost, and CO_2 neutrality or not, which could be regarded as a kind of sensitivity analysis.

6.3.6 Distributive consequences

Dalager *et al.* (1995) is the only study which directly performs an analysis of the distributive consequences for the various private parties, for instance, recycled paper companies, waste collectors, and treatment plants.

Ekvall and Bäckman (2001) and Radetzki present the cost for the relevant parties but do not estimate the private cost.

Table 6.11 External cost, per tonne of paper waste

	Currency	Production	Recycling	Incineration	Landfill
Bruvoll (1998)	NOK		408	552	1 392
Ekvall and Bäckman (2001) — EPS	SEK		20 to 1 500	2 700 to 6 400	1 400 to 5 000
Ekvall and Bäckman (2001) — ExternE	SEK		– 760 to 670	1 200 to 2 000	10 to 860
Ekvall and Bäckman (2001) — SU method	SEK		– 9 700 to 10 900	– 15 900 to 14 500	– 12 400 to 15 100
Hanley and Slark (1994)	GBP				5.85
Leach *et al*. (1997) — Low value (1)	GBP		45		
Leach *et al*. (1997) — High value (1)	GBP		375 to 450		
Petersen and Andersen (2002)	DKK			80	
Radetzki (1999)	SEK	811	700	424	1 451
Craighill and Powell (1996)	GBP		73.79		299.85

(1) Read from Table 8 in Leach *et al.* (1997).

7 Conclusions and outlook

The hypothesis assumed from the outset of this review was that many cost-benefit analyses on paper exist, and that it would be possible to gain some general insights from the existing studies. Surprisingly, the literature inventory has only identified a few studies that can be characterised as cost-benefit-like studies on paper, cardboard or paper packaging.

The present review has shown that there are significant differences between the studies and their comprehensiveness. This is particularly true as regards the environmental assessment. The objective of the studies varies, and only two studies are conducted for direct policy support, the rest of the studies are made as contributions to the policy debate.

A total of nine studies containing 41 scenarios are included in the final review:

- seven cost-benefit-like studies on paper;
- one cost-benefit-like study on municipal waste, where paper is a separate waste fraction;
- one study is a life cycle assessment where the externalities have been subject to monetary valuation.

7.1 Analysis of system delimitation and methodology

The objective of this project is to make a review of existing CBA studies and to identify whether they arrive at similar conclusions, and make a critical analysis of the assumptions underlying these conclusions. To meet this objective, a set of criteria for a 'good' CBA has been developed, based on guidelines from selected European countries and international organisations. From this exercise, the following general conclusions on system delimitation, extent of environmental assessment, and assumptions of the economic assessment can be made.

System delimitation

The system analysis and the parameters included or excluded in the studies vary substantially from study to study. Moreover, the system delimitation for the environmental assessment in a given study does not always match the system delimitation for the economic assessment in the same study. As an example, a study may include the economic cost of collection and recovery, but not the environmental emissions connected with these activities. However, the environmental and economic systems should in principle coincide in a given study, and it would increase the credibility of a study if any deviations from this were explained.

Roughly, four categories of system delimitation have been identified in the reviewed studies:

- studies covering the entire paper cycle (two studies);
- studies not including the upstream stage of virgin paper production, or not including wood as a limited primary resource (four studies);
- studies not including upstream processes, nor waste paper processing, but including the price of waste paper as an indication of the recycling value (two studies);
- studies excluding all paper life cycle stages except disposal and incineration combined with the avoided fossil energy production (one study).

The majority of studies include only the transport and waste management stages. This indicates a limited coverage of the paper cycle in the reviewed CBA studies.

In the LCA review preceding this CBA review, 15 system border criteria were identified that can be essential for the outcome of an environmental assessment. The criteria cover 15 choices to be made about the elements of the life cycle of paper, such as the alternative uses of wood, the choice of marginal energy sources for heat and electricity production in paper processing, or the waste management system in use. Only two of the nine CBA studies include half or more of the 15 criteria. Five of the remaining seven studies include two or less of the 15 criteria.

Extent of the environmental assessment

The limited coverage of the paper cycle in the reviewed CBA studies is also illustrated by the number of externalities, or emissions, included in the studies. The number of environmental parameters included in the studies varies from 2 to 28 where six of the studies include around 10 parameters. Considering the limited number of included externalities, it is questionable to what degree the studies can claim to cover all relevant consequences to the environment.

7.1.1 *CBA methodology and assumptions of the economic assessment*

By going systematically through guidelines from selected European countries and international organisations on CBA, six basic steps have been identified:

1. formulation of the problem/definition of the CBA;
2. description of consequences (scope definition);
3. monetary valuation;
4. discounting;
5. evaluation (net present value and conclusion);
6. evaluation of uncertainty.

None of the reviewed studies fully applies these basic steps for conducting a CBA. In particular, discounting is avoided by looking at one tonne of waste paper rather than making a scenario analysis of an entire waste system.

Depending on objective and choice of system delimitation, the studies exhibit large variations. In general, the conventional cost of waste management and sale of waste paper are included, although it is not always clearly described what exactly this cost covers. In addition to the conventional cost parameters, several studies have made a number of assumptions that are unique for the individual study. Moreover, in a couple of the reviewed studies, it has not been possible to recalculate the figures based on the information in the study.

Examples of how the economic methodology differs among the studies are:

- whether the study subtracts the external cost of a scenario by the value of environmental taxes already levied on certain emissions;
- whether the study includes an alternative interest rate for investment capital, or risk supplement for closure of landfills.

The monetary valuation of environmental externalities is still a subject of discussion among economists, scientists and decision-makers. In the studies reviewed that include monetary valuation, this discrepancy is reflected in significant differences in the prices ascribed to emissions.

7.2 Similarities in assumptions and conclusions

Depending on the assumptions made by the nine studies and 41 scenarios, a total of 18 conclusions are made concerning the priority between recycling, incineration, landfill and other treatment options.

The number of conclusions is higher than the number of studies because some of the studies analyse several waste paper fractions, sources of collection, or apply more valuation methods for estimating the external cost. The studies' scenarios and conclusions are presented in 'Annex III: Scenarios and conclusions'.

In 10 out of 18 cases recycling is preferred to any other option and in one of the remaining options recycling is preferred for the highest paper grade only. Incineration and landfill is preferred in four cases each.

7.3 Essential assumptions for the outcome of the studies

The second objective of this review is to assess the assumptions that have been essential for the outcome of a study. Little can be concluded in this respect. The main reason for this is the lack of transparency concerning the assumptions made in most studies, and the differences existing in system delimitation.

However, a few parameters that can be essential for the outcome of a paper CBA have been identified:

- time cost
- waste paper price
- system delimitation
- total external costs.

Time cost

The most significant parameter is the so-called time cost, that is, the value of households' time spent on sorting and transporting waste to recycling centres. Three studies have included the time cost, and it turns out to be a decisive element for the result of the study. In fact, if the time cost is excluded from the calculation, the conclusion changes towards being more favourable to recycling in three of the five cases. The reason is the huge influence of time cost assumed, varying from EUR 125 to 770 per waste paper tonne.

When the consideration of the time cost is excluded, 13 out of 18 cases prefer recycling and again in one of the remaining options recycling is preferred when it is the highest grade only.

Waste paper price

The waste paper price is essential for the conclusion in two studies. The study which has the most limited system boundary, the conclusion is mainly dependent on four variables: the waste paper price, investment cost, external cost and the price of coal. Another study concludes that if the waste paper price drops by 34 % this will change the conclusion. Considering the large fluctuations in the waste paper price observed in the last decades, this seems a real possibility.

System delimitation

With regard to the system delimitation, few studies have included the criteria considered key in LCAs. What is important for an LCA may not necessarily be important for a CBA, but the absence of a consideration may result in absence of knowledge of the relevance these key boundary criteria may have for the system comparison. Depending on which marginal energy source has been chosen, the inclusion of these key criteria is assumed to have a central influence on the conclusions.

External costs

The total external costs has a high influence on the conclusions in some of the studies due to their order of magnitude compared with other costs. Unfortunately, the environmental assessment is poorly described in most of the studies.

In general, the studies only present a monetary unit value connected to an environmental parameter, the total monetary value connected to the environmental parameter, or a summed monetary value for all externalities. This aggregated information gives the opportunity to identify whether the sum of externalities is important compared with other costs. However, if one wishes to analyse in detail the assessment of externalities and identify the importance of the individual parameters, the aggregated information is insufficient.

For an air emission such as NO_x the information needed to know, is, for example, the amount of emission assumed from transport and energy sector in rural and urban areas, the monetary unit value and the method used to develop the monetary unit value. Such information is generally not available in the reviewed studies. Therefore, it is not possible to specify which are the essential environmental parameters and why they are essential.

Air emission parameters are the most frequently included parameters. The four air emission parameters NO_x, SO_x, CO_2-fossil, and CH_4 cover more than half the times an air emission is included in the studies, and if particles and CO are included, these six parameters out of the 33 parameters to air cover 70 % of the times an air emission is considered.

In the CBA studies, there seems to be no clear correlation between the number of emissions covered and a preference for recycling, incineration or landfilling. The choice of high or low monetary values for certain emissions does not seem to influence the conclusion either. Most scenarios are a mixture of high values for some emissions and low values for others, but there is no real trend towards scenarios with relatively high values for all emissions and others with relatively low values.

7.4 Outlook

The conclusions presented above are not new. In a similar review of CBAs on municipal waste management, Lah (2002) concludes that the approaches used in CBA studies are often political, and that the research methods are often unclear or unreliable. The present review concludes that there is a general lack of consistent system delimitation, lack of transparency, and lack of consistency in the methodologies used to derive prices.

These conclusions are not to be considered as a general criticism of the CBA method as such. At present there appears to be a gap between how CBAs should be carried out in theory and how they are carried out in practice. Taking the reviewed CBAs as reference, the theoretical arguments for using CBA as a decision-support tool are confronted with the practical difficulties of using the reviewed CBAs to support a political decision.

Two main considerations have derived from this review. The first consideration is the potential for improvement of the quality of CBAs. The second is the challenge of using the result of national CBAs to support non-national, in other words, EU-level policies. These considerations have relevance for policy-makers making use of information from CBAs, researchers working with the theoretical development of the tool, and to practitioners facing the practical dilemmas.

7.4.1 *Potential for improvement of CBAs*

The review has shown that there is potential for improving the quality of the CBAs. This could raise the credibility of the information they provide to the policy-making process.

It has been concluded that one of the weakest parts of the reviewed CBAs has been the lack of a systematic approach to system analysis, ensuring that all relevant environmental and financial consequences are considered and are consistent. There is an apparent need of supplying CBA analysts with more thorough guidance on how to conduct system analysis in connection with cost-benefit studies. Inspiration could, for instance, be found in LCA guidelines. The LCA community has dealt with the challenge of system analysis through international collaboration, resulting in detailed and internationally standardised guidelines specifying how to conduct the goal and scope definition and inventory analysis of complex systems.

A CBA with a comprehensive environmental and economic assessment usually needs to merge several academic disciplines. The collaboration between technicians, such as engineers or physicists, and economists, could be strengthened, drawing on the skills of the different professional groups. Among other things, it could ensure that the technical system in any CBA is fully described and is consistent with the economic system.

Another area where improvements could be made is in the monetary valuation. This is particularly true as regards the number of currently available monetary values for externalities, the quality of the monetary values, and the methodology used to transfer these values from country to country. This could raise the credibility of the studies further. The European BeTa values are an example of a systematic development and application of monetary values to externalities, both at EU level and for the individual countries. At present, the BeTa values seem to be the most consistent values available. Having said that, they still only supply values for four parameters: SO_2, NO_x, $PM_{2.5}$ and VOCs.

7.4.2 *European policy-making based on national CBAs*

An objective of this review is to inform European policy-makers of whether the individual CBA studies gave conclusions pointing in the same direction. It has been shown that there is no clear answer to this question. However, even if there was a clear, common answer in several national CBAs, it is important to mention that policy-makers should be cautious in generalising the conclusion to supranational policy objectives.

As highlighted by Wenzel (2005) during the discussions of this review, most CBAs have a national scope, and analyse which alternative option that provides the socio-economic preferable situation within the national boundaries. When the system delimitation is national, the CBA describes the costs and benefits within the national border and consequences beyond the border are either ignored or not part of the costs and benefits.

CBAs typically provide information about the costs and benefits of marginal effects on the market covered by the system investigated. Thus, Wenzel sustains that the sum of independently national marginal changes within the EU may not necessarily be equal to an EU positive marginal change. In other words, making the same policy initiatives at a European level based on national CBAs can lead to substantial effects on the market such as changes in prices and market structures, which may not necessarily be socially beneficial in the long run.

While the national scope may be clear in an economic assessment, it is often the ambition of an environmental assessment to be global. The environmental assessment typically has a wider scope by including emissions stemming from the activities in and out of the country, and impacts are accounted for even though they may take place outside the country. One example is acidification, where emissions of SO_2 may arise in one country but, being transported by the wind, cause an impact to another country. Thus, strictly speaking, it could be argued that these environmental impacts should be deducted when the scope is national. Moreover, the monetary values of emissions are often estimated on the basis of the potential damage they cause within the national border rather than in the impact country. This discussion may be theoretical as it complicates the analysis even further but it serves to illustrate the difference between the environmental and economic assessment approaches.

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Annex 2: Complete list of contacts established with institutions in Europe

Search in databases, websites, and so on

To identify relevant studies, reports and articles, an initial broad search in a number of databases was conducted. Subsequently, the reference lists of the identified literature were examined in order to find other relevant studies.

The databases searched were:

- Danish Danbib
- Norwegian Bibsys
- Swedish Libris
- Waste Centre Denmark
- EBSCO*host* Electronic Journals Service
- ScienceDirect.

The key words used in the search were: waste, socioeconomic, economic, paper, cardboard, board, environmental economy, CBA, cost-benefit analysis, solid waste management.

The search words have been combined and translated into the national language (mainly English, Danish, Norwegian and Swedish) when needed for the national databases.

Contacts

Following the initial identification of studies, the libraries of a number of organisations and institutions were searched and subsequently the organisations were contacted. The institutions contacted are:

- Environment DG
- Eionet, European Information and Observation Network
- Statistisk sentralbyrå (Statistics Norway)
- ECON, Norwegian consultancy company specialised in socio-economic analysis
- CIT, Chalmers Industriteknik Company, Consultants in Environmental Management and Product Ecology
- NLH, Agricultural University of Norway
- GUA, Austrian consultancy company
- EPA, Norway
- EPA, Sweden
- EPA, The Netherlands (VROM)
- ETC/WMF consortium partners (Austrian EPA, Danish EPA, Irish EPA)
- RRF, Resources Recovery Forum
- CEPI, Confederation of European Paper Industry.

Persons contacted:

- Eionet NRCs on waste minimisation (one in each EEA country: 35, excluding Serbia and Montenegro, and Turkey);
- all 300 members of RRF have received a mail from the ETC/WMF requesting information on relevant studies;
- Terry Coleman, Environment Agency for England and Wales, and his network of international experts on LCA for integrated waste management has been contacted and received a request for information on relevant studies;
- Professor of Environmental Economies, Nick Hanley, University of Glasgow;
- Professor Arid Vatn, Department of Economics and Resource Management, Agricultural University of Norway;
- Matthew A. Leach, Centre for Environmental Technology, Imperial College of Science, Technology and Medicine, University of London, London SW7 2PE, United Kingdom;
- Esa Hyvärinen, CEPI.

Annex 3: Scenarios and conclusions

Table 1 Scenarios and conclusions

	Author	Scenario			Priority of conclusions
S1	Angst *et al.* (2001)	Reference year 1998, landfill of paper (with municipal waste) versus improved separate collection from households			1. Recycling 2. Landfill
		Maximum residual waste incineration versus improved separate collection from households			1. Recycling 2. Incineration
		Maximum biological-mechanical treatment versus improved separate collection from households			1. Recycling 2. Biological-mechanical treatment
S2	Bruvoll (1998) ([31])	Recycling		Commercial paper	1. Recycling
		Incineration			2. Incineration
		New landfill			3. Landfill
		Recycling		Residential paper	1. Incineration
		Incineration			2. Landfill
		New landfill			3. Recycling
S3	Dalager *et al.* (1995)	Increased recycling equals decreased incineration		Corrugated cardboard	1. Recycling (via decreased incineration or landfill)
		Increased recycling equals decreased landfill and incineration			2. Incineration
		Decreased recycling equals increased incineration			
		Decreased recycling, landfill equals decreased recycling			
		Increased recycling equals decreased incineration		Newspaper and magazines	1. Recycling (via decreased incineration)
		Increased recycling equals decreased landfill and incineration			2. Recycling via increased export
		Decreased recycling equals increased incineration			3. Incineration
		Increased export equals increased recycling			
		Decreased export equals decreased recycling			
		Increased recycling equals decreased incineration		Mixed paper	1. Recycling (via decreased incineration)
		Increased recycling equals decreased landfill and incineration			2. Recycling (via decreased landfill and incineration)
		Decreased recycling equals increased incineration			3. Incineration
S4	Ekvall and Bäckman (2001)	4a	Recycling	EPS method	1. Landfill 2. Recycling
			Incineration		3. Incineration Excluding time cost: 1. Recycling 2. Landfill
			Landfill		3. Incineration
		4b	Recycling	ExternE method	1. Landfill
			Incineration		2. Incineration 3. Recycling
			Landfill		Excluding time cost: 1. Recycling 2. Landfill 3. Incineration
		4c	Recycling	SU method	3. Incineration
			Incineration		4. Landfill 5. Recycling Excluding time cost: 1. Landfill 2. Recycling
			Landfill		3. Incineration

([31]) The study includes a scenario entitled 'Tax, commercial paper/residential paper', which is not included in this review. The reason is that the scenario is calculated in an economic model, where only the conclusion is available.

	Author	Scenario		Priority of conclusions
S5	Hanley and Stark (1994)	Recycling of paper compared with landfill		1. Recycling 2. Landfill
S6	Leach *et al.* (1997)	6a High externality values	CO_2 neutrality of paper	1. Recycling 2. Other options
			Non-CO_2 neutrality of paper	
		6b Low externality values	Non-CO_2 neutrality of paper	1. Other options 2. Recycling
			CO_2 neutrality of paper	1. Highest grade, recycled 2. Lower grades, other options
S7	Petersen and Andersen (2002)	Incinerating 5 % of collected paper 1996–2000 instead of recycling		Supports incineration of poor grade waste paper
S8	Radetzki (1999)	Recycling of packaging material		1. Landfill and incineration
		Recycling of newspapers		2. Recycling newspaper
		Incineration		3. Recycling packaging
		Landfill		(the values of landfill and incineration are the same) Excluding time cost: 1. Recycling newspaper 2. Recycling packaging and landfill and incineration (the values of recycling packaging, landfill and incineration are the same)
S9	Craighill and Powell (1996)	Recycling compared with landfill of newspapers and magazines		1. Recycling 2. Landfill

Table 2 Priority

	First priority	Second priority	Third priority
Recycling	10	5	3
Landfill	3	4	1
Incineration	3	5	1
Other options	1	2	0

Note: Two extra options not presented in the table are (1) landfill and incineration has equal first priority, (2) highest grade recycled first priority, lower grades not recycled second priority.

Table 3 Priority, excluding time cost

	First priority	Second priority	Third priority
Recycling	3	1	0
Landfill	1	2	0
Incineration	0	0	3
Other options	0	0	0

Note: An extra option not presented in the table is that in one case the conclusion is that there is no difference between the options.

The nine studies and 41 scenarios give 18 conclusions concerning the priority between recycling, incineration, landfill and other treatment options. In 10 out of 18 cases recycling is preferred to any other option and in one of the remaining options recycling is preferred when it is the highest grade only.

When the consideration of the time cost is excluded, 13 out of 18 cases prefer recycling and again in one of the remaining options recycling is preferred when it is the highest grade only.

Incineration and landfill are preferred in four cases each.

Annex 4: Inclusion of 15 key criteria

Table 1 Inclusion of 15 LCA key criteria

No	Dalager *et al.*, 1995c	Ekvall and Bäckman, 2001	Angst *et al.*, 2001	Leach *et al.*, 1997	Hanley and Slark, 1994	Petersen and Andersen, 2002	Bruvoll, 1998	Craighill and Powell, 1996	Radetzki, 1999	SUM: N/A plus No	SUM: Yes
1	N/A	No	N/A	No	No	No	No	N/A	No	9	0
2	No	No	N/A	No	No	No	No	N/A	No	9	0
3	Yes	No	N/A	Yes	No	No	No	N/A	No	7	2
4	Yes	Yes	Yes	Yes	No	No	No	N/A	N/A	5	4
5	Yes	N/A	Yes	N/A	No	No	No	N/A	N/A	7	2
6	Yes	Yes	N/A	N/A	No	No	No	N/A	N/A	7	2
7	Yes	N/A	Yes	N/A	No	No	No	N/A	N/A	7	2
8	N/A	N/A	N/A	No	No	No	No	N/A	N/A	9	0
9	Inc. landfill	Inc. landfill	Inc. landfill plus bio.-mech.	Inc. landfill	Landfill	Inc.	Tax, Inc. landfill	Landfill	Inc. landfill	—	—
10	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	No	2	7
11	yes	No	yes	No	No	yes	No	N/A	N/A	6	3
12	no	Yes	Yes	Yes	No	Yes	No	N/A	N/A	4	5
13	Yes	Yes	N/A	N/A	No	No	No	N/A	No	7	2
14	yes	yes	yes	yes	yes	No	No	N/A	N/A	4	5
15	Yes	N/A	yes	No	No	No	No	N/A	N/A	7	2
Yes	11	6	8	5	2	2	1	1	0		

Table 2 The studies monetary unit values

	S2	S1	S4a	S4b	S4c	S9	S6a	S6b	S7	S5	S8	S3
	Bruvoll, 1998	Angst *et al.*, 2001			Ekvall and Bäckman, 2001	Craighill and Powell, 1996		Leach *et al.*, 1997	Petersen and Andersen,	Hanley and Slark, 1994	Radetzki, 1999	Dalager *et al.*, 1995c
Value per tonne emission	1995 NKK/t	ATS/t	SKK/t	SKK/t	SKK/t	GBP/t	GBP/t	GBP/t	DKK/t	GBP/t	?	
CO_2 fossil	358	870	918	391	400	4	26	2	260	x	?	-
CH_4	18 156	18 270	23 120	4 420	7 800	72	11 400	1 400	x	3	?	-
NO_X	49 000	28 000	18 105	18 250	34 500	1 270	16 400	1 400	35 000	x	?	-
Particles	2 020 000	7 000	360 000	27 931	31 501	8 980	10 700	1 400	x	x	?	-
CO	117	1 050	x	1 419	x	6	2 900	1 400	x	x	-	-
NMVOC	11 000	28 000	x	x	121 000	x	x	x	x	x	-	-
SO_X	17 000	35 000	27 795	21 956	53 251	2 584	12 900	1 400	30 000	x	?	-

Annex 5: Economic conclusions in studies

This annex presents the main conclusions and some key economic assumptions made by the studies. Key economic figures are presented too.

S1: Angst *et al.* (2001)

The scenario paper 1 is understood as follows.

- In the reference 1998 scenario, the 8 % paper (33 500 tonnes) is not landfilled with the mixed waste but is recovered instead. In the maximum MVA scenario, the paper is recovered instead of being incinerated with mixed waste or treated in a mechanical-biological treatment plant with the mixed waste.
- The specific paper collection costs are generally held constant, in other words, marginal cost is nil, as the paper-container density is increased and containers have been moved to more central locations, and so on.

Main conclusion:

- the benefit of avoiding landfilling of paper is much higher in the reference 1998 scenario than in the two other scenarios, that is, the total avoided cost is higher.

Comments:

- the crucial parameter in the reference 1998 scenario is clearly the avoided external cost; the direct financial cost (or private cost) also influences the result;
- in the maximum MVA and the MBA scenarios, the direct financial cost (or private cost) is the major parameter influencing the results;
- Angst *et al.* (2001, p. 80) conclude that introduction of pre-treatment of the mixed waste at the mechanical-biological treatment plant has the largest influence on the cost-benefit balance, even if it is assumed that landfill closure cost is low (ATS 200 compared with ATS 2 000). The pre-treatment cost is ATS 1 700 per tonne.

S2: Bruvoll (1998)

Main conclusions:

- for residential paper waste, incineration has the lowest social cost, the second best option is landfilling and recycling is the third best option;
- for commercial paper, the results follow the 'waste hierarchy': recycling is the preferred option, followed by incineration and landfilling.

Comments:

- for residential paper, the households' recycling collection costs (time cost) of NOK 1 003 is an important parameter, but not quite enough to change the result from being in favour of incineration to recycling;

S1: Angst *et al.* (2001): Treatment scenarios

	Reference 1998	Max. MVA	Max. MBA
Mixed waste	52 % landfill	70 % incineration	64 % biological
Paper	+ 8 % recovery	+ 8 % recovery	+ 8 % recovery

S1: Angst *et al.* (2001): Results, scenario paper 1, ATS million/year

	Mixed waste1998	Max. MVA	Max. MBA
Total avoided cost	95	32	56
Direct financial cost	31	23	35
Substituted financial effects	6	2	5
Environmental cost	58	7	16

Note: Scenario paper 1. Commercial paper waste is not included, only household waste paper. Positive values are benefits, negative ones are costs.

S2: Bruvoll (1998): Results, NOK per tonne

	Residential paper waste	Commercial paper waste
Recycling	2 410	831
Incineration	1 319	1 455
New landfill	2 258	2 394

S2: Bruvoll (1998): Conventional collection costs including external costs, NOK per tonne

	Residential paper waste	Commercial paper waste
Recycling	1 312	981
Incineration/landfill	604	740

S2: Bruvoll (1998): Collection costs (time cost), NOK per tonne paper waste

	Residential paper waste	Commercial paper waste
Recycling	1 003 (290–1 716)	—

S2: Bruvoll (1998): Processing costs, NOK per tonne

	Residential paper waste	Commercial paper waste
Recycling	95	– 150
Incineration	714	714
New landfill	1 554	1 554

S2: Bruvoll (1998): External costs, NOK per tonne paper waste

	Residential and commercial
Recycling	408
Incineration	552
New landfill	1 392

- for residential paper, the conventional collection and processing costs of recycling are higher than for other treatment options;
- for commercial paper, the external cost of incineration and landfill ensure that recycling is the lowest social cost option;
- for commercial paper, the price of sold waste paper plays a minor role in supporting the result;
- the external costs support the waste hierarchy, in other words, the external cost from recycling is lower than external cost from incineration, which is lower than external cost from landfill.

S3: Dalager *et al.* (1995)

Main conclusions:

- increased recycling (scenario 2) leads to a considerable benefit for society;
- increased export of paper waste to Sweden also generates a benefit, although significantly lower than scenario 2.

Comments:

- The export price of the final recycled products is an important factor for a result which is favourable for recycling. The products are exported at prices of:
- corrugated cardboard: DKK 11 955 per tonne (EUR 1 600);
- recycled paper: DKK 4 600 per tonne (EUR 620);
- core: DKK 2 744 per tonne (EUR 370);
- recycled liner: DKK 2 143 per tonne (EUR 290);
- in the newspaper recycling scenarios, the estimated private profit (benefit) of one of the companies is rather extensive.
- The study does not include external cost.

S3: Dalager *et al* (1995): Scenarios, newspaper, 1000 tonne

	Recycling	Incineration	Landfill	Export
Scenario 2A	+ 45	– 45		
Scenario 2B	+ 45	– 29	– 16	
Scenario 3	– 54	+ 54		
Scenario 4A				+ 45 (to recycling)
Scenario 4B				– 54

S3: Dalager *et al* (1995): Newspaper, annual cost per tonne, DKK

	Production recycled paper	Separate collection of paper	Incineration paper	Landfill paper	Collection for incineration	Substitution energy	Export	Total
Scenario 2A	6 060	– 788	616		252	– 244		5 897
Scenario 2B	6 060	– 788	– 359	279	252			5 444
Scenario 3	– 5 974	863	– 616		– 378	244		– 5 861
Scenario 4A		– 788	616		252	– 244	346	182
Scenario 4B		863	– 616		– 378	244	– 346	– 233

Note: Positive values are benefits, negative ones are costs.

S4a-c: Ekvall and Bäckman (2001)

Main conclusion:

- the total cost using the EPS and ExternE methods favours landfilling, whereas the total cost using the SU method favours incineration.

Comments:

- The households' time spent on sorting, transport and lost income is a determining factor for the results using the EPS and ExternE methods for estimating external costs. Excluding it will change the result in favour of recycling. No other parameters seem to have a significant influence on the result.
- For the SU method, the result seems very solid and no parameters seem to be able to change the result. However, the time cost has a significant influence on the results and so has the external cost which heavily supports incineration.
- The external costs estimated via the EPS and SU methods do not support the waste hierarchy:
- EPS method: the external cost from recycling is lower than external cost from landfill, which is slightly lower than external cost from incineration;
- SU method: the external cost from incineration is significantly lower than the external cost from landfill, which again is significantly lower than external cost from recycling.
- The environmental taxes paid are deducted from the estimated environmental cost.

S4a-c: Ekvall and Bäckman (2001): Net private cost, SEK per tonne

	Cost, including uncertainty	Estimated cost
Recycling	1 800–2 200	1 923
Incineration	1 100–1 700	1 450
Landfilling	1 000–1 600	1 320

S4a-c: Ekvall and Bäckman (2001): External cost, SEK per tonne

	EPS method (S4a)		ExternE method (S4b)		SU method (S4c)		Environmental taxes
	Cost, including uncertainty	Estimated cost, env. taxes deducted	Cost, including Uncertainty	Estimated cost, env. taxes deducted	Cost, including uncertainty	Estimated cost, env. taxes deducted	
Recycling	20–1 500	796	– 760–670	– 716	– 9 700–10 900	3 127	759
Incineration	2 700–6 400	4 531	1 200–2 000	1 641	– 15 900–14 500	– 721	– 798
Landfilling	1 400–5 000	3 185	10–860	436	– 12 400–15 100	916	420

S4a-c: Ekvall and Bäckman (2001): Time cost, SEK per tonne

	Cost, incl. uncertainty	Average value (1)
Recycling	280–6 450	3 350
Incineration	30–1 440	780
Landfilling	30–1 440	780

(1) Estimated by the ETC/RWM.

S4a-c: Ekvall and Bäckman (2001): Total cost, SEK per tonne (1)

	EPS method	ExternE method	SU method
Recycling	6 069	4 557	8 400
Incineration	6 761	3 871	1 509
Landfilling	5 285	2 536	3 016

(1) Estimated by the ETC/RWM.

S5: Hanley and Slark (1994)

Main conclusion:

- the result favours recycling of paper (1 920 tonnes per year).

Comments:

- the costs include solely collection-related costs from kerbside collection of paper;
- external cost includes avoided emissions of methane and scarcity value (an area or land cost).

Sensitivity analysis showed that (Hanley and Slark (1994, p. 195):

- the outcome was most sensitive to a decrease in the collected tonnage: a 15 % fall would reduce the annualised NPV to zero;
- if the price paid for waste paper falls by GBP 4.63 per tonne, from GBP 13.67 to 9.04, the result breaks even;
- if the avoided costs decrease by 49 % to GBP 4.85 per tonne, the result breaks even;
- if the collection costs increased by 17 %, the result breaks even.

S6: Leach *et al.* (1997)

Conclusions made by Leach *et al.* (1997):

- 'With low values assigned to environmental externalities, recycling of all paper grades is the optimal choice. However, with higher values attached to environmental impacts, other waste options offer lower total costs and are selected.'
- 'With (these) higher externality values, carbon neutrality suggests that zero recycling is optimal, whilst with carbon emissions from renewable sources counted, the highest grade of paper is still recycled.'
- 'The case study has shown that recycling waste paper may not be the best use of this resource. Many environmental impacts of alternative management options, such as incineration and anaerobic digestion, are lower. Moreover, these options lead to lower total social costs when environmental externalities are assigned relatively high, but reasonable values.'

S5: Hanley and Slark (1994) Costs and benefits, total cost and per tonne

Costs	GBP	GBP/t	Benefits	GBP	GBP/t
Operational staff wages	31 403	16.36	Sales revenue	26 240	13.67
Indirect expenditures	10 923	5.69	Avoided disposal cost	18 240	9.50
Vehicle purchase/maintenance	8 888	4.63	Avoided methane emissions	5 760	3.00
Vehicle insurance	600	0.31	Scarcity value saving	5 472	2.85
Protective clothing	397	0.21	Avoided collection cost	5 376	2.80
External costs	0	0	Existence value	0	0
Total	**52 211**	**27.19**	**Total**	**61 088**	**31.82**

S6: Leach *et al* (1997): Operation cost, GBP per tonne

	Average	Grade 1	Grade 2	Grade 3
Kerbside collection and sorting	60			
Waste paper price		160	50	40
De-inking and re-pulping		90	40	30
Incineration	55			
Anaerobic digestion	45			
Landfill charge	30			

S6: Leach *et al* (1997): Average cost of delivered paper, GBP per tonne (1)

	Total	Operation	Resource	Energy	Externalities (2)
Low externalities	535	200	190	100	45
Low externalities — CO_2 neutral	535	200	190	100	45
High externalities	1 050	75	425	100	450
High externalities — CO_2 neutral	965	50	440	100	375

(1) Read from Figure 7.

(2) Read from Figure 8.

S6: Leach *et al* (1997): Total cost per tonne waste, GBP per tonne (1)

	Incineration	Anerobic digestion	Landfill, energy recovery	Landfill, no energy recovery
Low externalities	25	30	25	30
High externalities	– 45	– 10	40	70

Note: Positive values are costs, negative ones are benefits.

(1) Read from Figure 9.

S7: Petersen and Andersen (2002)

Main conclusion:

- in general, the result supports the incineration of (poor grade) waste paper with production of energy which replaces energy based on coal.

Comments:

- cost for collection of waste paper and production/recycling of paper are not included in the analysis;
- the analysis is sensitive to the price of waste paper: if the paper price increases to more than

S7: Petersen and Andersen (2002): DKK per tonne paper, 2000 prices

Incinerated paper	**1996**	**1997**	**1998**	**1999**	**2000**
Price, paper	129	48	63	191	616
External cost, incineration of paper	80	80	80	80	80
Investment cost	116	115	107	98	93
Sub total	325	243	250	369	789
Avoided cost, coal					
Substituted energy (tonne coal per tonne paper)	0.6	0.6	0.6	0.6	0.6
Price, coal	244	275	273	225	258
Value of saved coal	– 147	– 166	– 165	– 136	– 156
External cost, saved emissions from coal	– 448	– 448	– 448	– 448	– 448
Sub-total	– 595	– 614	– 612	– 583	– 603
Result	**– 270**	**– 370**	**– 362**	**– 214**	**186**

Note: Positive values are costs, negative ones are benefits.

DKK 400 per tonne, the benefits of incinerating paper become lower than the costs;
- other parameters that may influence the result are the price of coal and investment cost.

S8: Radetzki (1999)

Main conclusion:

- the result supports the landfilling and incineration of newspapers and packaging.

Comments:

- The main reason for the conclusion is extremely high costs for the households to sort, rinse and transport newspaper and packaging to bring banks. If the time cost is excluded, the result would be in favour of recycling of newspapers.
- The analysis assumes that the net cost of collecting newspapers are nil, as the sale of waste paper carries a revenue that covers the collection cost.
- A parameter of minor influence is the avoided environmental cost from production of virgin products.
- The environmental taxes paid are deducted from the estimated environmental cost.

S8: Radetzki (1999): SEK per tonne paper

	Recycling, packaging	Recycling, newspapers	Incineration	Landfill
Private net cost (producers), conventional collection and treatment	2 220	0	1 500	1 200
External cost:				
• Time cost, sorting and transport (households)	32 500	6 500	0	0
• Environmental cost	389	700	513	960
• Deduction, environmental taxes	– 130	– 233	– 171	– 320
Saved production of virgin products:				
• Environmental cost	– 948	– 811	0	0
• Environmental taxes, raw materials	316	270	0	0
Result	**34 347**	**6 426**	**1 842**	**1 840**

Annex 6: Presentation of the four guidelines

European Commission impact assessment handbook

In this section the European Commission impact assessment handbook is presented.

The aim of the handbook ([33]) is to contribute to an effective and efficient regulatory environment and further, to a more coherent implementation of the European strategy for sustainable development. The handbook contains a section explaining how the process of impact assessment will be implemented in the Commission, gradually from 2003, as well as an annex of the main components of the impact assessment and technical guidelines. The guide is not specific to environmental projects but should be applied for all major initiatives.

According to the handbook, the 'impact assessment methodology identifies the likely positive and negative impacts of proposed policy actions, enabling informed political judgements to be made about the proposal and identify trade-offs in achieving competing objectives. It also permits to complete the application of the subsidiarity and proportionality protocol annexed to the Amsterdam Treaty'.

Objective of impact assessment

The guideline stresses that it is 'an aid to decision-making, not a substitute for political judgement'. The impact assessment guide has a broader scope than the traditional CBA as an impact assessment also considers distributive effects and obstacles to compliance with other legislation, which are not contained in the narrower framework of the CBA methodology.

The Commission's handbook deals with identifying and assessing alternative policies to present policy. The handbook presents 'road maps' for each step in an impact assessment. The guide provides a common set of basic questions, minimum analytical standards, and a common reporting format that integrates the previous sectoral assessment methods concerning direct and indirect impacts of a proposal.

The handbook has much focus on how to make sure that the right problem is addressed, and it identifies four steps to go through. They are as follows:

- identify the problem to be addressed, stating why it is a problem and its causes;
- state the objectives of the policy;
- identify alternative policy options;
- subsequently, select relevant options.

After the system has been identified and described, the subsequent assessment, where the CBA methodology is applied, has the following steps:

1. identification of impacts
2. identification of 'winners' and 'losers' (distributive effects)
3. measurement of impacts
4. comparison of impacts
5. consideration of risks and uncertainties.

Identification of impacts

When identifying impacts a number of things should be considered. Taking an initial broad picture helps focusing on relevant impacts and distributive effects, where both short-term and long-term impacts should be considered. The links from cause to effect (the proposal to the impact) should be clearly stated. This includes setting up assumptions about factors that are outside the scope of the study, and particular attention should be paid to interactions and feedback mechanisms within both the system in focus and cross-boundary interactions. An example of the latter is the implementation of other proposals that may affect the impacts in focus.

The core issues addressed by the concept of sustainability are maintaining a certain level of stocks of resources (natural, human, social and manmade), efficiency and equity. Thus the impacts on the three core issues of sustainability must be assessed to describe positive and negative effects.

([33]) European Commission, *A handbook for impact assessment in the Commission*, European Commission, Brussels, 2002.

The three core issues are:

- protection and renewal of stocks of resources;
- technical efficiency with which resources are used to produce goods and services;
- equity within and between generations.

Distributive effects

In the analysis of distributive effects two types of impacts should be considered: impacts on different social and economic groups, and impacts on existing inequalities.

According to the handbook, the aim is to looks at the losses and gains of all parties concerned by the intervention. The costs included in a (budgetary) CBA relate to the EU budget (financial, administrative, human resources), the beneficiaries and target population (co-financing, administrative burden related to participation, and so on), and third parties such as Member States.

Impacts on existing inequalities include, for example, regional impacts if the project in consideration is likely to further increase regional disparities.

Measurement of impacts

Focus is on impacts on society, thus when there is a difference in private and social costs it should be accounted for. Private costs are defined as the cost incurred by a particular sector or group because of a policy measure. In contrast, the social costs are the costs of a policy to society as a whole.

It should be noticed that while private costs may include taxes, social costs do not. Taxes are a burden on the private sector, whereas this private cost is offset at the level of society as a whole by the revenues received by the tax collecting authority.

The measurement of impacts should be in qualitative, quantitative and monetary terms where appropriate. It is important in the valuation of monetary costs and benefits that they are made comparable by expression in real terms, which is after adjustment for inflation. Double-counting should be avoided and thus it should be avoided counting costs that are passed on to consumers as higher prices. It is also important to remember that taxation is a redistribution of revenues in society as a whole and should thus be withdrawn from private costs.

Costs of goods and services that have already been incurred or are already irrevocably committed, also called 'sunk costs', should be left out.

Values of non-market impacts are to be found through WTP and WTA studies. When possible benefit transfer can be used.

Discounting

To be able to present the net present value, costs and benefits must be expressed in real terms. A constant discount rate of 4 % is to be applied ([34]), unless very long time horizons are involved; in such cases a lower discount rate may be appropriate.

Presentation of results

When comparing options and presenting results, the overall good practice is to secure transparency that allows for reproducibility, allowing others to be able to arrive at the same results, using the same data and methods. The results should also be checked for robustness. If using different methods or assumptions to estimate the impacts gives very different results, the reliability of the analysis may be questioned.

When presenting a result it is important to remember that impact assessments do not necessarily generate clear-cut conclusions or recommendations regarding the final policy choice. Good practice when presenting the analysis results is to present each option rather than a single, take it or leave it, option ([35]). The individual impacts that make up the NPV should always be presented together with the overall NPV.

Part of the presentation of a result is to give a clear and transparent summary of the benefits and costs to society, where impacts are presented in a qualitative, quantitative, and monetary form where possible and proportionate. Aggregated results should be presented in a disaggregated form to secure transparency.

([34]) This broadly corresponds to the average real yield on long-term government debt in the EU since the early 1980s.
([35]) Integrated assessments should be presented in a way that directs decision-makers to the key factors to weigh in their decision, highlighting trade-offs, risks and uncertainties, rather than making judgements in place of the decision maker', OECD, 2004: 4. Recommendation of the Council on assessment and decision-making for integrated transport an environment policy, Endorsed by environment ministers on 20 April 2004, Adopted by the OECD Council of 21 April 2004.

If the alternative options to be compared have different time horizons, annualised values are calculated to secure comparability.

Part of the result presentation is to clearly present the distributive effects and the critical assumptions and uncertainties followed by a description of the data and the analytical methodology used.

The advantage of this process for the decision-maker is that it highlights trade-offs, it helps to improve the design of options to maximise win-win situations and it identifies accompanying measures needed to mitigate such as disproportionate negative distributive effects.

Risk and uncertainty

The risk estimates should be reported in a way that reflects the degree of uncertainty present in the data and does not create a false sense of precision. In some cases, the level of uncertainty may be too high to make precise quantified estimates. In these cases, ranges of plausible values could be given. It is important to try to make some assessment of the possible over-, or under-estimation of the assessed impacts. The guide presents various ways to do so.

Appraisal in the United Kingdom, central government

In this section, the Green Book ([36]), which is a best practice guideline for all central departments and executive agencies in the United Kingdom, is presented.

The guideline aims at making the appraisal process throughout government more consistent and transparent. The Green Book presents a framework for 'appraisal, whereby government intervention is validated, objectives are set, and options are created and reviewed, by analysing their costs and benefits'. The authors emphasis that, 'cost-benefit analysis is recommended with supplementary techniques to be used for weighing up those costs and benefits that remain unvalued'. By following the guideline the following two questions should be answered.

- Are there better ways to achieve this objective?
- Are there better uses for these resources?

The Green Book takes the analyst through the phases of the appraisal and evaluation circle consisting of six phases (rationale, objectives, appraisal, monitoring, evaluation, and feedback). Of particular relevance for CBA is the appraisal of the options.

Appraisal of options

On the basis of the best estimate of the costs and benefits of an option (the so-called 'base case'), alternative options are created and reviewed to help decision-makers understand the potential range of the decision that they may take.

System delimitation

When assessing the system boundaries the guideline states that 'in situations where expenditures or activities are linked together and the costs or benefits are mutually dependent, the proposal must be appraised as a whole'. However, the components' individual contribution must be taken into account. The meaning of the previous two statements is that a thorough systems analysis has to be conducted to make sure that interactions both within the system and cross-boundary are not forgotten. It is the costs and benefits, both direct and indirect, to the United Kingdom, that the appraisal should take account of. However, also impacts on non-UK residents and firms should be identified and quantified separately where it is reasonable to do so, and where the impacts might affect the conclusions of the appraisal.

Valuation of quantified impacts

After the identification and quantification of impacts, they have to be valued. In cases where no values are found, a central estimate together with a plausible maximum and minimum can be applied. It is not an argument to exclude a cost or benefit just because it cannot be ascribed a monetary value. All impacts must therefore be clearly described, and should be quantified where this is possible and meaningful. Sunk costs, costs that have already been incurred, should be ignored.

A range of valuation techniques exists to be able to apply a value to costs and benefits with no expressed market value.

The value of time is used in the appraisal of, for example, road schemes. The value of working time is equal to the opportunity cost of the time to the employer. The value of non-working time has a national average for transport appraisals.

([36]) HM Treasury, *The Green Book, Appraisal and Evaluation in Central Government,* Treasury Office, London, 2003.

However, non-transport appraisals contain no recommendations for value of non-working time and it is not clear whether or not the value of time counts for other projects than transport projects at all.

The guideline includes general recommendations for the valuation of health benefits, prevented fatality and injury, design and land and buildings based on WTP and WTA. It explains that the valuation of environmental impacts is difficult.

Adjusting prices

According to the guideline, adjustments are often needed after ascribing impacts a monetary value. The guideline stresses that 'as for all adjustments, they should be shown separately, clearly and explicitly'. Adjustment of prices relates to taxes, relative price changes and discounting.

It is appropriate to adjust for taxes when there are differences in taxation between options. If a tax is a transfer payment it should be excluded from the appraisal, as it is not a direct economic cost to society.

If relative price changes are expected to develop more than inflation, adjustments should be made reflecting the expected change in prices. Examples of goods that change prices over time are high-technology products, fuel prices and wages.

The recommended discounting rate is 3.5 %. However, for very long-term impacts over 30 years, a declining schedule of discount rates should be used. The schedule is presented in the Green Book.

Presentation of result

Transparency is important when presenting results, so that it is absolutely clear on what basis decisions are taken. 'It is important to avoid being spuriously accurate when concluding from, and presenting the results of, data generated by an appraisal'.

Adjustment of the result due to risks and uncertainties should always be conducted and presented with the result of the appraisal.

According to the guideline proposals should generally not proceed if, despite an overall net benefit to society, there is a net cost to the United Kingdom (i.e. after taking into account external costs).

The Danish Ministry for the Environment

In this section the Danish guideline to socio-economic analysis is presented.

This extensive guideline ([37]) to socio-economic analysis is produced for the appraisal of environmental policy and project proposal. However, it also gives guidance on describing the economic and environmental consequences. The guideline divides socio-economic analysis into three categories.

The categories are: financial analysis, welfare-economic analysis, and economic analysis with national focus as presented in Table VI.1.

Formulation of the problem/definition of the project

The guideline stresses that a clear and thorough definition of the project and formulation of the problem is crucial. The question of which changes in activity the project generates is essential, because it creates the basis for a correct specification of the project's consequences, which should be included in the analysis.

Table VI.1 Three categories of socio-economic analysis

Financial analysis	Welfare-economic analysis	Macroeconomic analysis
Accounting of direct economic costs for affected parties. Excluding effects on environment. Suited to describe distributive effects on income	Accounting of direct and indirect socio-economic consequences for society as a whole. Includes effects on environment. Suited for assessment of marginal changes. CBA is in this category	Accounting of direct and indirect economic effects for society as a whole. The focus is effects on employment, GDP, public and private consumption, and so on. In practice, this analysis is difficult to conduct for single projects. Effects on the environment are measured in their physical units

([37]) Møller *et al.*, *Socioeconomic appraisal of environmental projects* (in Danish), the National Environmental Research Institute, the Danish EPA, and the Danish Nature and Forest Agency, 2000.

Table VI.2 Table of consequences

Quantities	Period 1	Period 2	Period 3	....	Period T
Economic consequences					
Supply of traded consumer goods					
Consumption of production factors:					
• labour					
• fixed capital (buildings, machinery, etc.)					
• environment (renewable such as agricultural land, forests, fishing waters)					
Consumption of raw materials:					
• exhaustible resources such as hydrocarbons and metals					
• renewables such as drinking water					
• currency balance					
• export and import of goods and services					
• unilateral transfers (EU subsidies, etc.)					
Direct environmental consequences					
Various types of environmental impact (emissions, noise, physical load, etc.)					
Consequences of the environmental impact on the environment's productivity as production factor					
Consequences of the environmental impact on living conditions of the population (health, amenity value, cultural value, etc.)					
Indirect environmental consequences					
Production of inputs					
Avoided consequences					

Source: Møller *et al.* (2000).

In doing so, a number of aspects must be considered. First, the entire baseline scenario (the situation prior to the implementation of the project or policy proposed) must be described. Next, activity changes caused by the project must be assessed. In relation to this, it should be considered whether the project represents a new activity in society or if it replaces an existing activity.

To help in deciding a geographical scope of the project, which should reflect the affected persons, the reallocation of resources being proposed should be described, so as to determine the population influenced by costs and benefits.

Description of consequences

When the project has been defined all consequences resulting from its implementation should be defined. The consequences are measured in their physical units such as kg, m^3, and so on. The guideline suggests a table of consequences as the procedure applied to get a hold of the relevant consequences to include in the analysis.

The point of departure for the analysis is a pure national focus. However, the guideline recommends describing the consequences inside the country as well as the ones that take place outside the national borders. Likewise, which consequences arise due to transboundary emissions and to the production of imported goods should be described.

The guideline does not make specific recommendations as regards the time horizon of a project. Often the economic lifetime of the project will be equal to the physical lifetime.

However, environmental impacts may have a longer time horizon.

Monetary valuation

In the welfare-economic analysis, the prices express the marginal willingness to pay ([38]). As the prices paid by manufacturers to produce goods are not including all costs faced by the consumer, market prices have to be calculated. In practice, the producer costs (prices excluding VAT, taxes, subsidies, and so on) are raised with a so-called 'net-levy factor', which is supposed to reflect the general level of levies in society ([39]). This way, prices reflect market prices and thereby the marginal willingness-to-pay for goods. The prices of imported and exported goods are also raised by a net-levy factor ([40]).

The producer prices include all non-refundable levies such as green taxes. However, VAT is excluded.

The valuation of environmental goods can be conducted in a number of ways and is an expression of WTP and WTA. According to the guideline it is only relevant to value changes in the quality or availability of environmental goods — it is of little relevance to assess the total value of environmental goods. It is also only relevant to make a valuation if the change in environmental quality is within common public acceptance.

If the objective of the analysis is to study whether alternative A or alternative B is (generally) preferable to society, then it is assumed that all investments are made from scratch. However, if the objective is to study what is preferable to society here and now, then already made investment should be regarded as 'sunk cost' (Danish EPA, 2003).

If a public project is financed through increased taxes, the tax distortion should be included (Danish EPA). The Ministry of Financial Affairs has estimated that the marginal costs for every DKK 1 collected in tax, are DKK 0.2. Thus, all public spending is raised by a factor of 1.2. However, up until now the Danish EPA has not included the tax distortion directly in the analysis, but presented it as a sensitivity analysis.

Discounting

The guideline recommends using a constant social discount rate of 3 % with 1 % and 5 % as sensitivity analyses. For investments, the social discount rate is combined with an interest rate of 6 % for alternative investments.

Overall welfare economic evaluation and uncertainty

The recommendation based on the analysis is in principle the net present value. However, when presenting the income distribution uncertainty, ethics and aesthetics should be considered. Income distribution is dealt with through the budget economic analysis. Uncertainty is often particularly related to the description of environmental consequences. No recommendation is given for how to include ethics and aesthetics in the evaluation.

OECD, recent developments in CBA

In this section the draft OECD report on recent developments in CBA is presented.

This draft report ([41]) does not provide recommendations but restricts itself to present recent discussions on selected topics in relation to environmental CBA.

The three main areas dealt with are as follows:

- the lack of a market for environmental goods and the subsequent difficulties of including environmental goods;
- discounting;
- the accuracy of willingness-to-pay (WTP) and willingness-to-accept (WTA) and the distributive effects of applying these measures for costs and benefits.

The stages in a CBA according to Pearce *et al.* (2004) are as follows:

- the questions to be addressed (describing the policies to be assessed)
- the issue of standing (delimitation to relevant impacts)
- assessment of impacts
- impacts and time horizons (delimitation of time horizon)
- finding money values (monetary valuation)
- discounting and accounting for rising relative valuations
- risk and uncertainty assessment
- presentation of the result.

The questions to be addressed

The first part of the CBA is the goal definition where the whole process of identifying and describing the relevant policies is conducted. The

([38]) The guideline includes a comprehensive description of prices for several production factors. The presentation here aims at giving an introduction to the principles.
([39]) The net-levy factor is estimated as the relation between the GDP and the GFI. During a number of years, the factor has been 1.17. Thus, the general pressure from levies is 17%.
([40]) The net-levy factor for internationally traded goods is 1.25.
([41]) Pearce, D., Mourato, S., Atkinson, G., *Recent developments in environmental cost-benefit analysis, Draft chapters*, OECD Environment Directorate, 2004.

report makes use of a set of questions to make sure that the CBA addresses the right problem.

The issue of standing

The second part of the CBA is the system delimitation, where it is defined whose costs and benefits count. The delimitation, in general, follows the scope of the policy. Traditionally, policies have the focus of the population of a nation. A broader perspective should be applied in situations where a policy relates to a context with an international treaty or some accepted ethical reason exists for counting costs and benefits on non-nationals.

Assessment of impacts

Any impact of the assessed policy that affects the well-being of the individuals of relevance has standing. Tracing and measuring impacts is a necessary precursor to the valuation of those impacts. When it comes to environmental concerns LCA and EIA are used. The monetary valuation of impacts is conducted by revealing individuals' preferences for and against the impacts.

Equity and CBA

Pearce *et al.* (2004) stress that it should be clear that equity is a central question for discussion when assessing costs and benefits of a policy or project. Even if it is decided not to conduct an assessment of distributional consequences the question might arise into the CBA, for example by not counting the costs and benefits that arise beyond political or national boundaries or within certain groups.

The sections on equity discuss the trade-off between efficiency and equity to examine how far a CBA can be moderated in the light of equity considerations. Pearce *et al.* (2004) do not provide a clear recommendation of whether or not it is a good idea to include distributive concerns and the quest for equity in the CBA itself or consider the concerns in a separate analysis. The implication of including equity in a CBA is that the analyst has to tackle problems in relation to both efficiency and equity. The CBA becomes an analysis of the (for society) tolerable trade-off between efficiency and equity. The report outlines the main approach to the examination of the distributive issues of concern to the cost-benefit analysts.

Impacts and time horizons

A number of arguments exist on how to decide on the relevant time horizon. However, there are no hard and fast rules. Some argue that it should follow the physical or economic life of a project. Others argue for delimitation based on when costs and benefits are insignificant due to discounting or according to the level of uncertainty of future impacts.

Monetary valuation

Once the physical impacts have been measured they must be expressed as the preferences of individuals. The very basis of the CBA is to reveal the preferences of individuals through willingness-to-pay and willingness-to-accept valuations for market and non-market goods to find a measure for change in welfare. The report gives an overview of the stage of development of preference methods, which are used to present a value on intangible impacts, or non-market goods. The methods are central to a CBA as, according to the theoretical foundation, they are the only way to ensure that the non-market goods (and policies resulting in such impacts) receive sufficient scrutiny in economic analyses compared with other policies and market goods.

A benefit is technically measured by the WTP to secure the benefit, whereas the loss of a benefit is described through the WTA compensation for the loss. According to the report, the practice of CBA tends to mix approximations to WTP with some direct measures of WTP, and WTA tends to get little attention. There is a considerable body of empirical analysis suggesting that WTP and WTA are not the same. The report describes how to handle this problem in various situations.

The value of health is very important in a CBA concerning environmental questions. The report goes through the recent debate and development in the value of statistical life (VOSL), value of a life year (VOLY) and age.

Environmental problems are associated with immediate and future risks. Pearce *et al.* (2004) emphasises that 'age is very relevant for the valuation of future risks. Thus a policy which lowers the general level of exposure to pollution should be evaluated in terms of the (lower than present VOSL) valuations associated with younger people's valuations of future risks, plus older persons' valuations of that risk as an immediate risk'.

Discounting and accounting for rising relative valuations

The costs and benefits of a particular project will most often fall at various points in time. To calculate the NPV of a project, future costs and benefits must be calculated into equivalent present values. This is what discounting does, in other words, the opposite of compound interest.

Discounting is defended by the argument that it reflects the way people behave and value things (Hanley and Spash, 1993). Discounting can be justified on two grounds: social time preference and the marginal productivity of capital. The concept of social time preference explains that people, in general, prefer benefits to occur now rather than later and costs to occur later rather than now (Turner *et al.*, 1994). Therefore, impacts in the near future should be weighted higher than impacts in the far future. The second argument is that capital is productive. Hence a need to adjust the impacts to the costs of today arises.

The report states that discounting is the process of applying less weight to future impacts (costs or benefits) than present impacts, which is sometimes referred to as 'The tyranny of discounting'. The debate of discounting can be strong both for and against discounting and regarding various discount rates. Various standpoints are examined and the report draws up the conclusion that a declining discount rate should be applied. However, a specific declining rate is not recommended. The declining discount rate has a theoretical rationale based on uncertainty about the future development in economy and interest rates. It is also argued through 'a significant body of evidence suggesting that people do not behave as if their discount rates are a constant', however declining over time.

Inflation is a simple rise in the general price level, which should be netted out to express the base year. The relative price changes are different in the sense that they reflect a change in the elasticity of willingness to pay for goods. For example, it could be assumed that an environmental asset diminishes over time, and thus attracts higher value.

Risk and uncertainty assessment

A risk is a situation where the costs/benefits are not known with certainty, but a probability distribution is known. In a situation of uncertainty the probability distribution is unknown.

In the case of risk the report describes various decision rules. In the case of uncertainty then, at the very least, it is required that a sensitivity analysis is performed.

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European Environment Agency
Kongens Nytorv 6
1050 Copenhagen K
Denmark

Tel.: +45 33 36 71 00
Fax: +45 33 36 71 99

Web: www.eea.eu.int
Enquiries: www.eea.eu.int/enquiries

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European Environment Agency