ENVIRONMENTAL BENEFITS OF RECYCLING
An international review of life cycle comparisons for key materials in the UK recycling sector

Foreword

A recurring theme in the debates that surround waste and resources management is the extent to which the recycling of materials offers genuine benefits to the environment. Often, critics of the policy drive towards greater recycling assert that the act of recycling may in fact have little or no benefit to the environment, suggesting that more energy may be used in getting materials to the recycling facility than is saved by the process of recycling.

In order to inform this debate more fully, WRAP (the Waste & Resources Action Programme) commissioned a major international research project from the Technical University of Denmark (IPU) and the Danish Topic Centre on Waste. The Danish team of experts , who have worked closely on the development of life-cycle thinking to inform future European waste strategies, conducted a comprehensive international review of existing life cycle analysis (LCA) projects that have used ISO standard methodologies to evaluate the impact on the environment of managing key materials in different ways – through recycling, incineration or landfill.

This study is the largest and most comprehensive international review of LCA work on key materials that are often collected for recycling – paper/cardboard, plastics, aluminium, steel, glass, wood and aggregates. Of several hundred studies that were screened, 55 'state-of-the-art' LCAs were selected for detailed review, comprising over 200 different scenarios, each one an LCA in its own right.

The review recognises that a key issue with LCA work on complex products and waste management systems is that it often produces contradictory findings in attempting to analyse similar systems. This is due to differences in the assumptions made, the system boundaries that are set and the interpretation of the results.

By conducting a large scale international review, and using rigorous criteria to 'sift out' those studies with less robust methodology and assumptions, the result is a far more objective review of the environmental impacts of different waste management systems for those key materials than any one individual study can deliver.

The results are clear. Across the board, most studies show that recycling offers more environmental benefits and lower environmental impacts than other waste management options.

Further analysis by WRAP of the research findings has provided an assessment of the relative greenhouse gas savings associated with current UK levels of recycling for paper/cardboard, glass, plastics, aluminium and steel.

Again, the results are clear and positive. The UK's current recycling of those materials saves between 10-15 million tonnes of CO_2 equivalents per year compared to applying the current mix of landfill and incineration with energy recovery to the same materials. This is equivalent to about 10% of the annual CO_2 emissions from the transport sector, and equates to taking 3.5 million cars off UK roads.

The message for policy makers and practitioners is unequivocal. Recycling is good for the environment, saves energy, reduces raw material extraction and combats climate change. It has a vital role to play as waste and resource strategies are reviewed to meet the challenges posed by European Directives, as well as in moving the UK towards more sustainable patterns of consumption and production and in combating climate change by reducing greenhouse gas emissions.

The environmental benefits demonstrated by this study show that it is time for recycling to take its rightful place at the heart of sustainable waste management and resource efficiency, and reinforce its clear contribution to reducing greenhouse gas emissions.

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Executive Summary

Life Cycle Assessment (LCA) is one of the most widely used and internationally accepted methods for the evaluation of the environmental impacts of products and systems. An LCA is a calculation of the environmental burden of a material, product or service during its lifetime.

LCA has been used in the last decade to compare the environmental impacts of different options for the handling of waste. However, the application of LCA to such complex systems presents significant challenges, the most important being whether or not the interactions between a waste system with its surrounding technosphere have been properly characterised. Different assumptions around such interactions have often resulted in LCAs which apparently analyse the same material system but produce very different conclusions. A key objective of the present review was therefore to build a greater understanding of the critical factors that determine environmental preferences between waste management options, taking into account overall life cycle impacts and underlying assumptions.

With the purpose of identifying state-of-the-art research on the environmental impacts of waste management, an extensive search has been conducted for seven material categories of key significance to the recycling sector: paper/cardboard, plastics, glass, wood, steel, aluminium and aggregates. Preference has been given to studies following scientifically valid and if possible standardised assessment methodologies, preferably LCA methods meeting the standards of the International Organisation for Standardisation.

The international literature search contained three main elements:

1) targeted approach to LCA institutions and experts worldwide;
2) A broad search of the scientific literature;
3) An international Internet search via search engines and homepages of relevant institutions (mainly national Environmental Protection Agencies).

The search resulted in the identification of several hundred potentially relevant references which were then sifted and short-listed for a more detailed review. The main criteria for inclusion were: that it should be a holistic environmental study, preferably an LCA, meeting a set of methodological quality criteria, that its results should be unambiguously ascribable to the material in question, and that it should include a comparison of two or more options for the waste management phase.

In total 55 studies were judged to represent the state-of-the-art knowledge on the environmental aspects of waste management. **Table ES1** summarises the number of studies evaluated and selected by material.

Table ES1: Number of studies evaluated and number selected for detailed review by material.

Material	Number of studies evaluated	Number of studies used	Number of scenarios identified
Glass	19	11	25
Wood	29	3	7
Paper and cardboard	108	9	63
Plastics	42	10	60
Aluminium	19	11	20
Steel	31	9	20
Aggregates	24	2	6

Each of the reviewed studies was a comparison between two or more waste management options. Each study comprised one or more scenarios of varying system boundary conditions and assumptions, each one being an LCA in its own right. The final set of studies related to a wide range of different geographical areas, including North America, Europe and the Antipodes.

Across the 55 studies the assumptions that were found to be most critical to the results were those that related to the interdependency between waste handling systems and the energy system of the surrounding technosphere, including:

- the type of energy used for the manufacture of primary materials;
- the type of energy used for the manufacture of secondary products from recycled materials;
- the type of recycling process applied.

The review has provided a systematic means of highlighting system boundary conditions that were significant to LCA outcomes. For six of the materials these can be condensed into the 16 key issues shown in **Table ES2**, relating to different life cycle stages. For paper and cardboard, a slightly different set of key boundary issues have been identified in **Table ES3**.

Table ES 2: Key system boundary issues in the LCAs excluding paper and cardboard.

Material production	Virgin material	
	1	Material marginal. Average or specific? Which?
	2	Electricity marginal: which? Hydro, biomass, coal, gas, oil, other?
	3	Steam marginal: which? Biomass, coal, gas, oil, other?
	4	Co-products dealt with? If Yes: By allocation? By system expansion?
	Secondary material	
	5	Material marginal. Average or specific? Which?
	6	Electricity marginal: which? Hydro, biomass, coal, gas, oil, other?
	7	Steam marginal: which? Biomass, coal, gas, oil, other?
	8	Co-products dealt with? If Yes: By allocation? By system expansion?
Ante - material recovery	9	Product dependent material recovery included? Yes/no
	10	Type of product dependent material recovery
Material disposal	11	Disposal comparison e.g.: recycling vs. incineration
	12	Emissions from landfill included? Considered/no information
	13	Energy from incineration substitutes heat? Considered/no information
	14	Energy from incineration substitutes electricity? Considered/no information
	15	Alternative use of incineration capacity included? Considered/no information
	16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other)

Table ES 3: Key system boundary issues in the LCAs 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 & landfilling 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?

The purpose of a comparative LCA is to reflect the environmental consequences of choosing one alternative over another. One of the requirements of the most recent LCA guidelines is that the processes and systems to be included are the marginal ones (those responding to a change in demand). In the energy sector, the concept of the marginal electricity is well known, being the electricity production that is turned on or off as a response to changes in demand. However, the review found that many LCAs still used the average energy production mix instead of marginal energy sources. Inevitably, such choices and inconsistencies can greatly influence the energy-related impact results of an LCA study.

The review has highlighted important differences that resulted from the way in which different LCAs have been constructed and these differences must be considered when drawing more general conclusions from the review. However, **Table ES 4** shows that from 188 scenarios that included recycling, the overwhelming majority of them (83%) favoured recycling over either landfill or incineration.

The environmental impact categories that featured in the review included energy use, resource consumption, global warming potential, other energy-related impacts, toxicity, waste generation and other impacts (such as on land use or biodiversity). The study developed a method for dealing with the complexities of LCA outputs through the use of summary graphs to represent the findings across different scenarios and environmental impact categories. **Figures ES 1-7** display results for greenhouse gas impacts for the seven materials, using the following method.

Table ES 4: Overall environmental preference of waste management options across all reviewed scenarios

	Recycling v. Incineration			Recycling v. Landfill		
Material	Recycling	Incineration	No preference	Recycling	Landfill	No preference
Paper	22	6	9	12	0	1
Glass	8	0	1	14	2	0
Plastics	32	8	2	15	0	0
Aluminium	10	1	0	7	0	0
Steel	8	1	0	11	0	0
Wood						
Aggregates				6	0	0
Totals	80	16	12	65	2	1

	Incineration v. Landfill			Recycling v. Mixed			Grand Total
Material	Incineration	Landfill	No preference	Recycling	Mixed	No preference	
Paper	1	0	0	12	0	0	63
Glass							25
Plastics	2	0	1				60
Aluminium	2	0	0				20
Steel							20
Wood	7	0	0				7
Aggregates							6
Totals	12	0	1	12	0	0	201

In order to explore the relative environmental benefits of whole life scenarios containing different waste management options, each scenario was represented by a numbered box, the first digit indicating the number of the study and second, the scenario within it (see **Appendix 5**). These were then placed along a scale of relative environmental burden, indicating which option had either more or less environmental burden than the other. If one scenario came up with a value within the same range as another, the boxes were then stacked in columns, indicating the frequency distribution of the results across the entire review for that particular material, impact category and waste management comparison.

Some of the reviewed studies only covered part of the life cycle, and could not be represented alongside whole life cycle scenarios. Such cases were placed off the scale of the graphs as a qualitative indication of the relative environmental impact of the comparison covered. These were indicated by boxes with dashed outlines placed off the scale on either the left or right hand side of the diagram, depending on the environmental preference.

Particular attention was given to quantification of the greenhouse gas implications of different scenarios, measured as CO_2-equivalents. In line with the overall findings, it was concluded that for paper/cardboard, plastics, glass, steel, aluminium and aggregates there was generally a greenhouse gas emission saving from recycling compared with either landfill or incineration. **Figures ES 1-7** summarise these findings using the graphing method described above. For wood, no credible comparative scenarios could be found that included recycling as an end of life option, so **Figure ES 4** relates to three LCAs that compared incineration with landfill.

In the case of glass, the review highlighted the importance of the type of recycling in determining the relative advantage compared with either landfilling or incineration. Closed loop glass recycling was found to be preferable to both incineration and landfilling in environmental terms, while certain types of ‘open loop’ glass recycling, such as glass into aggregates, appeared to be more marginal or even disadvantageous. However, this conclusion was based on a single study, so wider application to other materials would be misleading.

The review identified a number of significant gaps within the LCA literature and has also indicated boundary conditions and system assumptions should be given more attention in future work. The generation of more complete information on the life cycle wide environmental implications of alternative open loop recycling options for a range of materials was a case-in-point, as was the need for comparative LCAs for wood recycling against alternative options.

Figure ES 1: Paper and cardboard ~ comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options

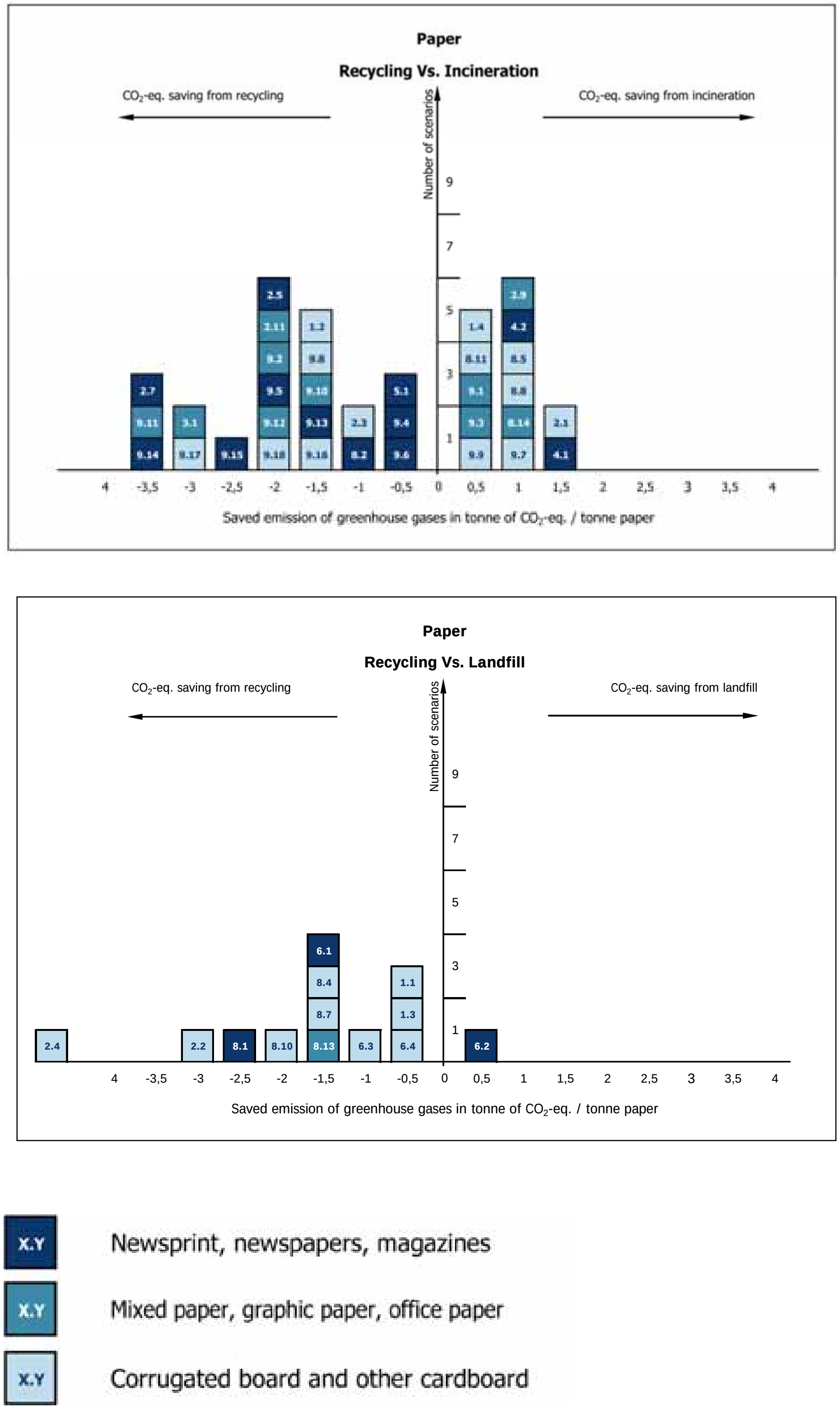
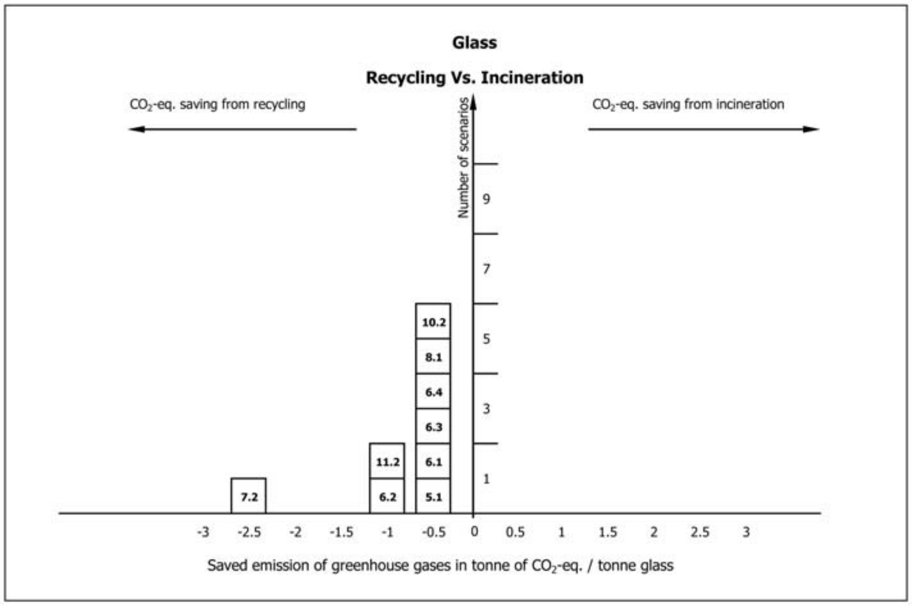
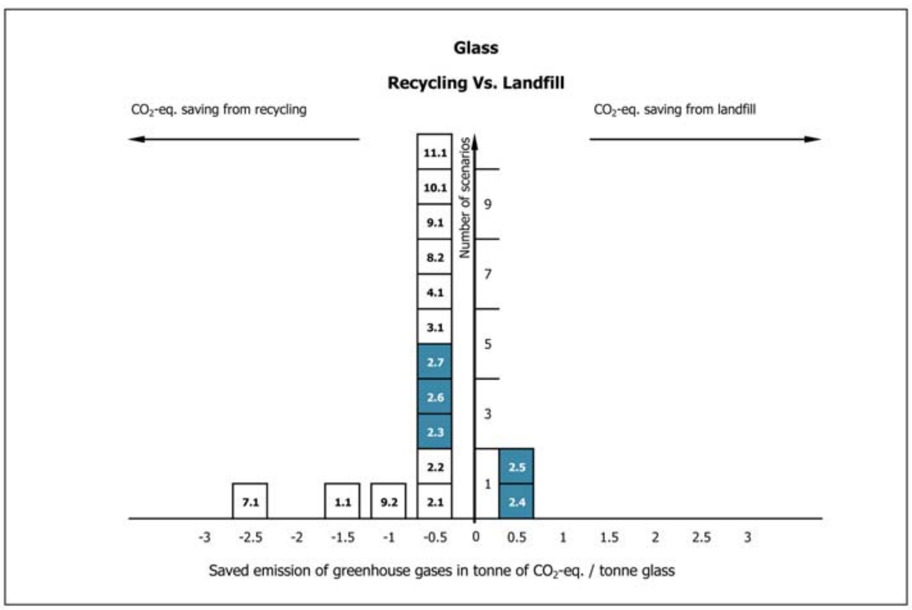


Figure ES 2: Glass ~ comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options





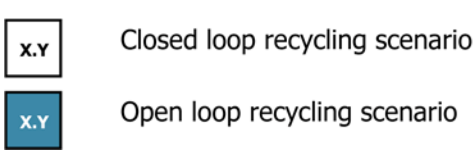
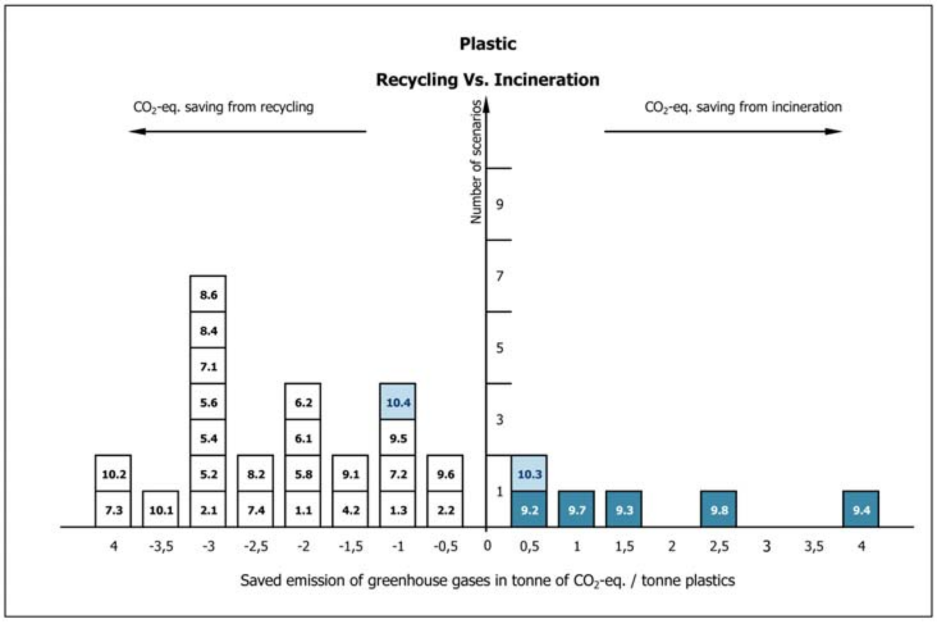
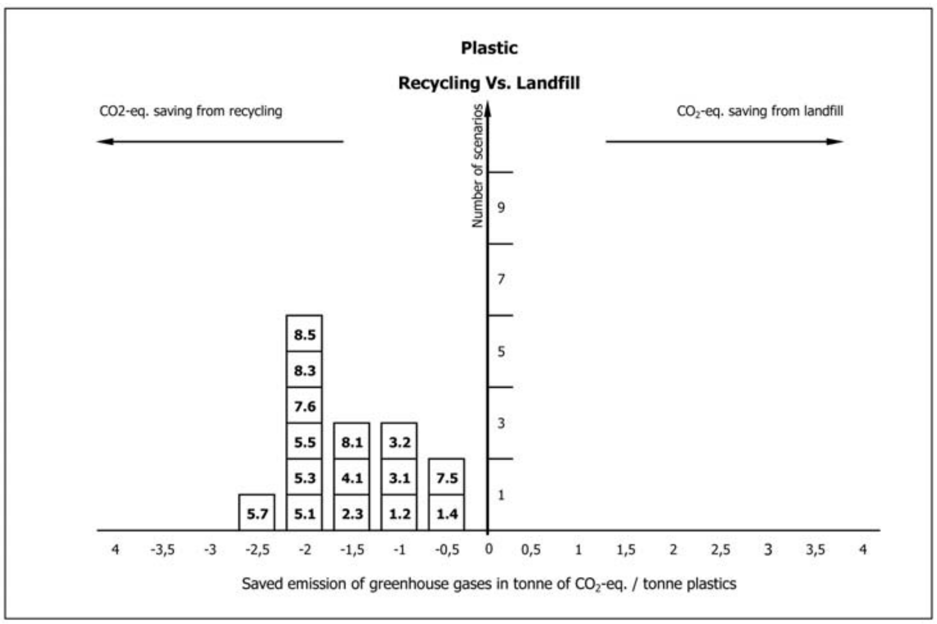


Figure ES 3: Plastics~ comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options





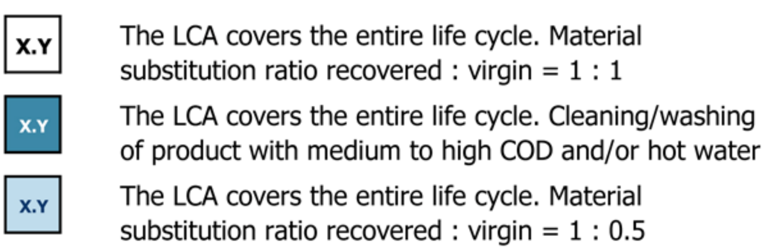


Figure ES 4: Wood ~ comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options

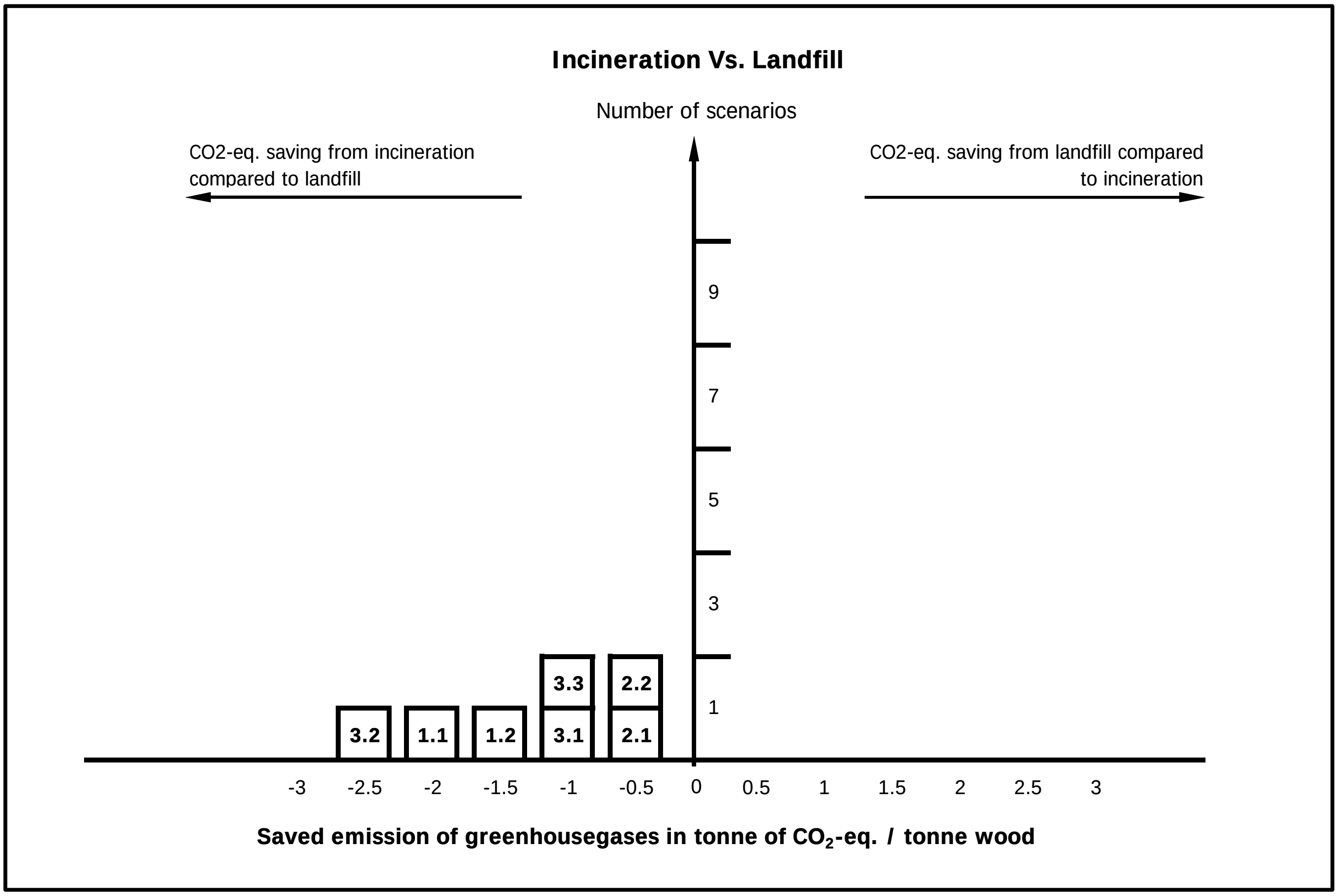


Figure ES 5: Aggregates ~ comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options

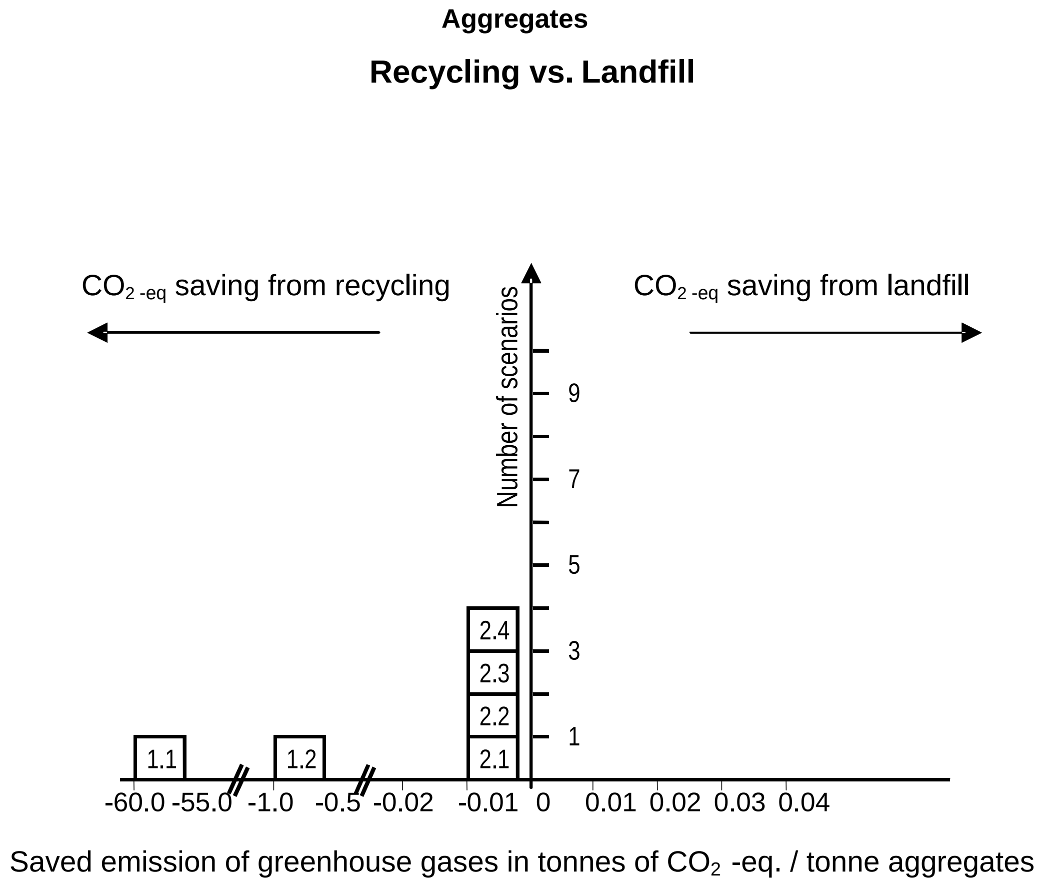
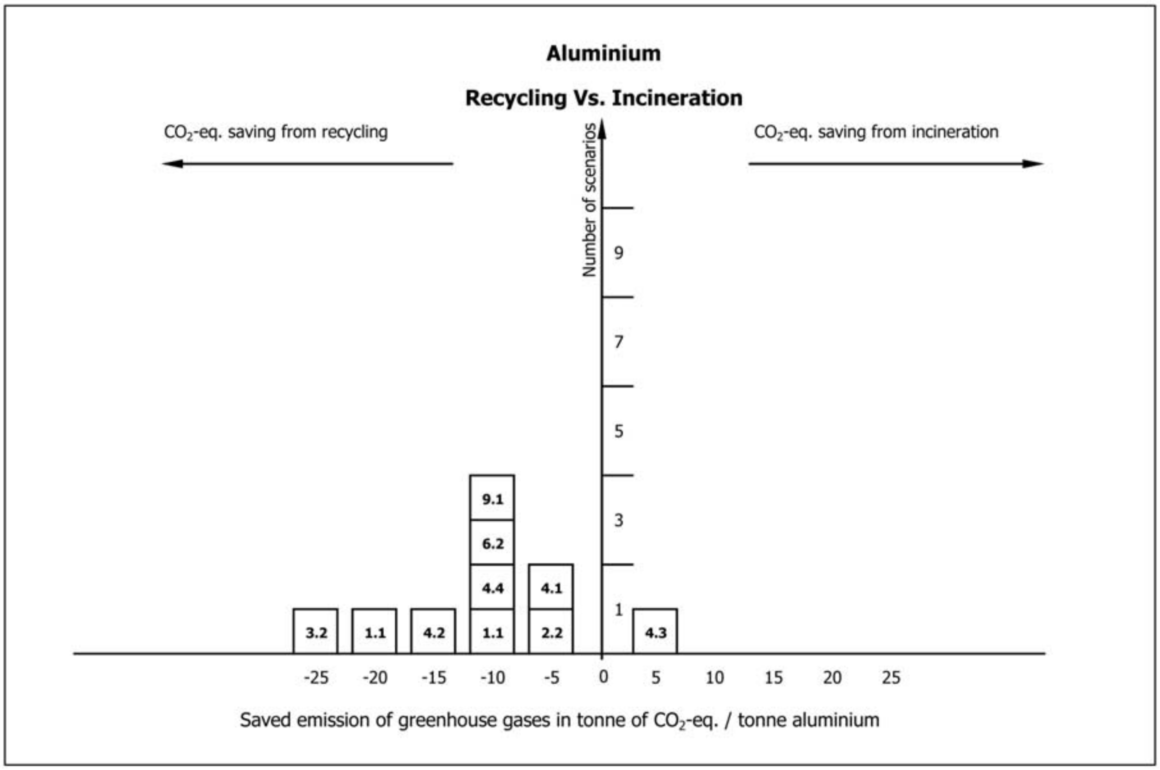


Figure ES 6: Aluminium ~ comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options



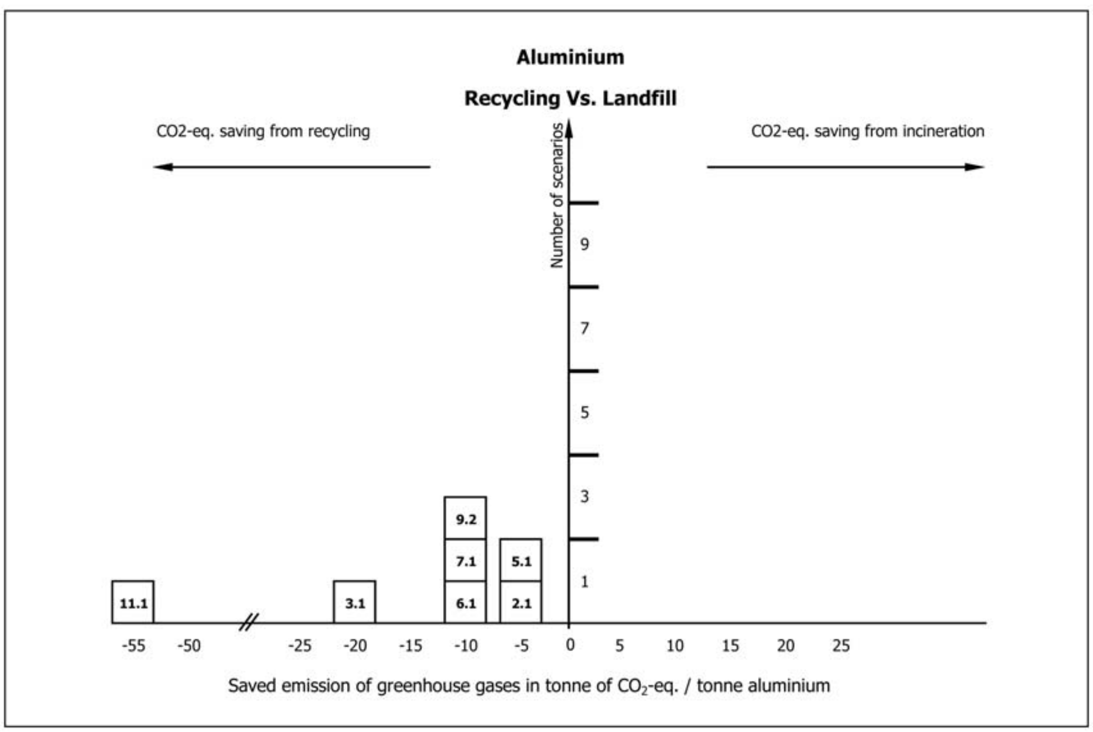
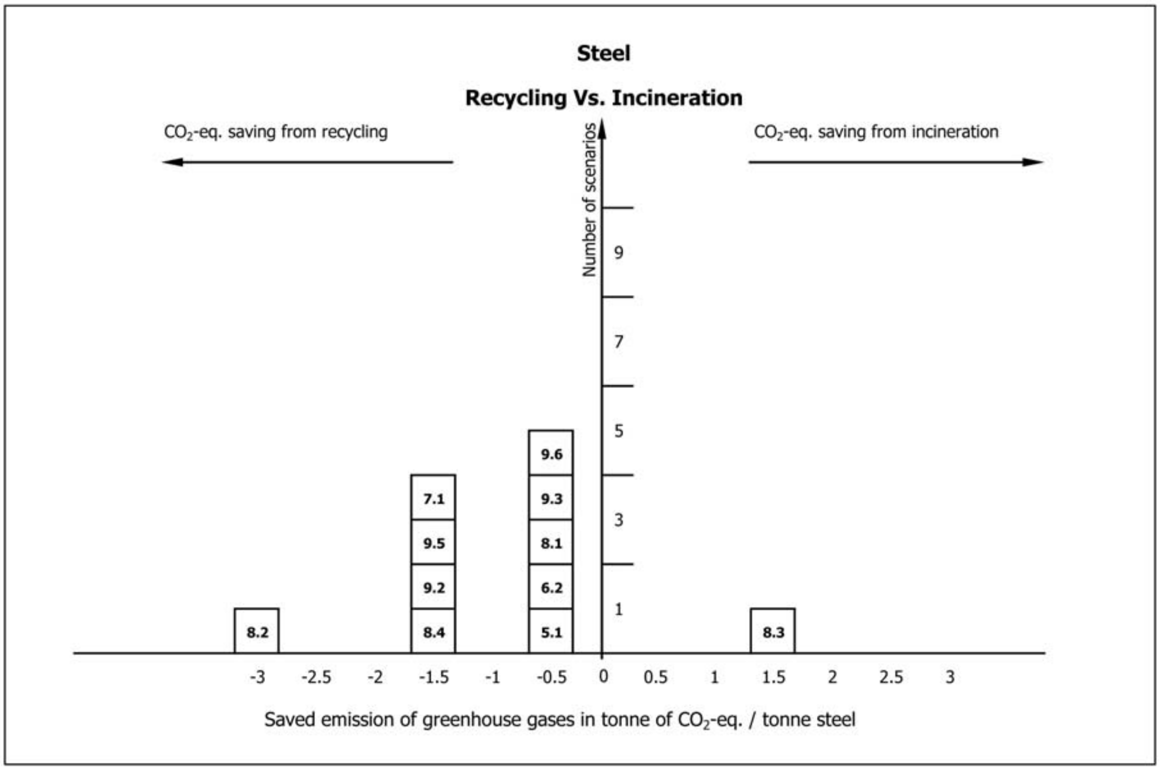
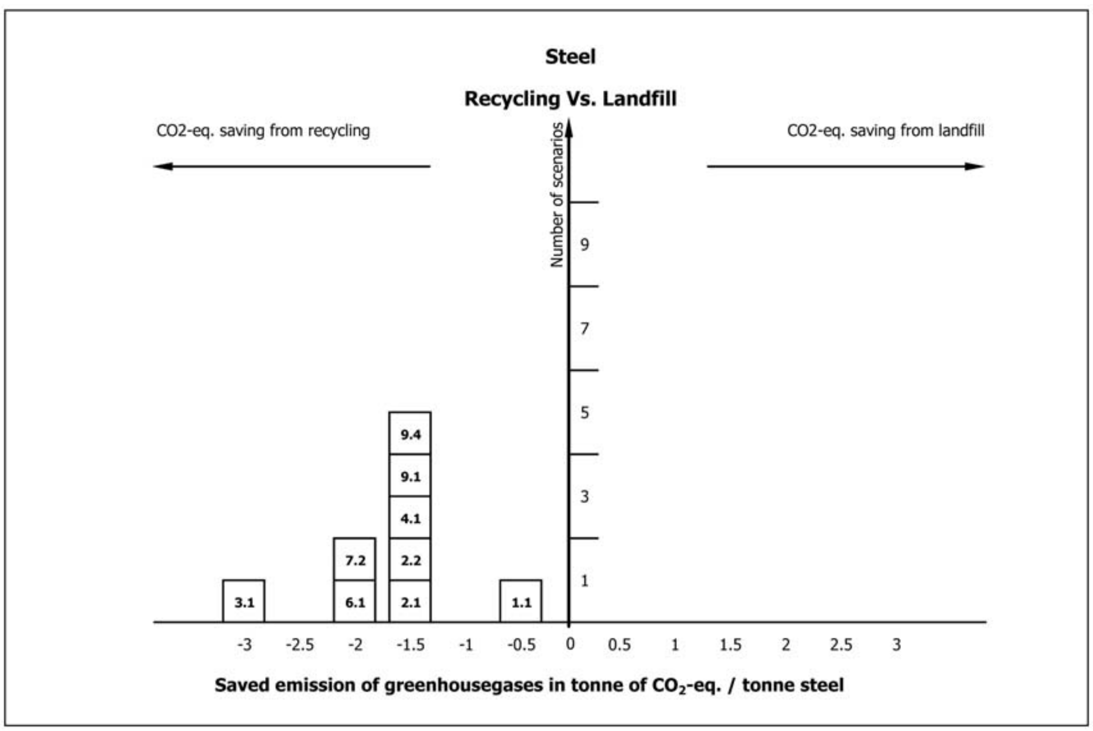


Figure ES 7: Steel ~ comparison of whole life cycle greenhouse gas savings from scenarios with different waste management options





1. Introduction

Across the European Union as well as within many of the individual Member States, waste management strategies and technologies have been the subject of much debate over the last decades. The EU has developed a hierarchy for prioritisation of waste handling options, based on assumed environmental burdens, with waste prevention at the top, and landfilling at the bottom:

waste prevention > re-use > recycling > energy recovery > landfilling

This 'hierarchy' has been regarded as a general 'rule-of-thumb' for prioritisation of waste strategies, and assumed to hold true in the vast majority of situations, while acknowledging that exceptions may exist for particular waste streams and localities.

More recently, however, and in line with the development of environmental assessment tools, some researchers and debaters have challenged the hierarchy. It is argued that it is too dogmatic and unjustified on scientific grounds, and that in some cases, environmental priorities may not follow the hierarchy that it implies.

Any statement about the environmental aspects of a waste management option must, of course, comprise all known environmental impacts of that option, and similarly any comparison of options must likewise be a holistic comparison capturing all essential environmental differences between the compared options. This calls for a holistic environmental assessment methodology such as Life Cycle Assessment (LCA).

The challenge for a holistic assessment tool such as LCA is that it analyses large, often complex systems, and it has to deal with the inclusion of the interactions of the studied system with its surroundings. The system boundaries are not always known or easy to identify, and these uncertainties leave room for interpretation and the use of assumptions. In some cases, these assumptions have resulted in LCA studies that apparently analyse similar systems - such as the recycling of a waste material versus its incineration – to arrive at very different conclusions.

These problems have been detected and acknowledged in the scientific communities involved with the research and development for LCA methodologies such as SETAC, the Society of Environmental Toxicology and Chemistry. Much effort has gone into developing and standardising methods in order to improve credibility and reproducibility of results and to promote the wider acceptance of LCA methodologies.

As a result of over a decade of comprehensive consensus work in the International Organisation of Standardisation, ISO, Life Cycle Assessment methods have now been standardised and the ISO 14040 series of LCA standards provides a good reference base for a greater consistency of approach. However, following the ISO standards is not in itself enough for ensuring the quality and transparency of an LCA.

The quality of LCAs in practice is still quite variable and, since the outcome of an LCA is very dependent on assumptions and system boundaries, so do the results and interpretation that follow. Undertaking a review of the environmental performance of any large, complex system, such as waste management, therefore requires a careful understanding of assumptions and boundary conditions in order to explain any disparities between results and conclusions.

1.1 Methodology and outline of the review

The aim of the study has been to identify and critically review existing LCA studies covering alternative waste management options for a selection of seven waste categories of particular significance to the recycling sector: paper/cardboard, plastics, glass, wood, steel, aluminium and aggregates. The methodology can be readily adapted to further materials in the future.

To this end, the system parameters and boundary assumptions that have been most decisive for the conclusions obtained in the reviewed LCA studies have been identified and assessed. The review has followed a methodology developed and used by members of the project team for a recent similar review of paper and cardboard (Villanueva et al., 2004). Based on this study and numerous similar LCA studies and reviews, it is the experience of the project team that the key issues for comparison and interpretation of results and conclusions from LCA studies fall into three main categories:

1. System boundary assumptions, including issues of system equivalence, identification of marginal process technologies, system delimitation, time-frame definition, and geographical coverage
2. Impact assessment categories and weighting procedures
3. Data age, source and quality

These categories have, therefore, been the ones addressed in the present project, and they have shaped the template used for the review.

For some of these issues, LCA methodology clearly states which delimitations, assumptions and other methodological choices are correct and which are incorrect. For other issues, there may well be no right or wrong answer, but they may be scenario-dependant or geographically dependant. In such cases, LCAs should ideally comprise sensitivity analyses applied to the assumptions and methodological choices that are essential to the results and conclusions. Based on the LCA expertise and experience of the project team and on any sensitivity analyses contained within the reviewed LCAs, the review has evaluated the correctness and the robustness of results and conclusions for each of the 55 reviewed LCAs. In case a reviewed LCA did not include sensitivity analyses on essential assumptions and choices, the project team has carried out an experience-based evaluation of the sensitivity to such assumptions and choices.

The search plan for identifying existing LCA studies is detailed in **Appendix 1**.

2. Framework for the selection and assessment of LCA studies

This section describes:

1. the criteria used to select the studies
2. the criteria used to review the selected studies

2.1 Selection criteria

The identification of studies for detailed review has required the definition of a set of selection criteria. On the one hand, these criteria were used to narrow the search in line with the review goals. On the other hand, the criteria ensured that only transparent, high-quality studies were selected. The three main selection criteria were:

1. The study was to be an LCA or LCA-like study.

2. The material stream in question was analysed and reported on separately, that is, not as a part of a mixed waste stream.

3. The study included a comparison of one or more scenarios for the end-of-life handling of the material stream in question.

In addition, secondary criteria were used to complement the main criteria. These included factors such as the perspective of the study (product, company or societal perspective), the publication year and whether or not the data were original.

The studies were selected exclusively on the grounds of their quality, measured against these criteria. The most limiting factor in the selection process was the requirement that the study contained a comparison of the environmental impacts of two or more options for the management of waste. Thus, all studies fulfilling this criterion using a holistic environmental approach, preferably LCA methodology or similar, were included in the review. These studies were judged by the authors to represent the state-of-the-art knowledge on the environmental aspects of waste management. The selection criteria are described in more detail in the next sections.

2.1.2 Studies must be LCAs or LCA-like studies

LCA studies were preferred because they have to follow minimum requirements on, amongst other things, structure, methodology, quality and transparency as described by the ISO standards. Fulfilment of these standards facilitates the cross-comparison of results from different studies.

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 was to analyse in detail a series of LCA studies, evaluate their conclusions and deduce, if it is possible to make a generalisation from these conclusions. It has been observed that not all LCAs analysing the management of the same waste materials have arrived at the same conclusions (Björklund and Finnveden, 2005).

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 any differences in the LCA methods used, and consider how they affect the results. Therefore, it is advantageous if the LCA studies analysed fulfil certain criteria that make them comparable, and if possible conform to 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, which was used as a reference in the present study.

Within the requirements of the ISO14040 standards, the following criteria have to be observed:

- A life cycle assessment must include the phases of goal and scope definition, inventory analysis, impact assessment, and interpretation of results (**Figure 2.1**).

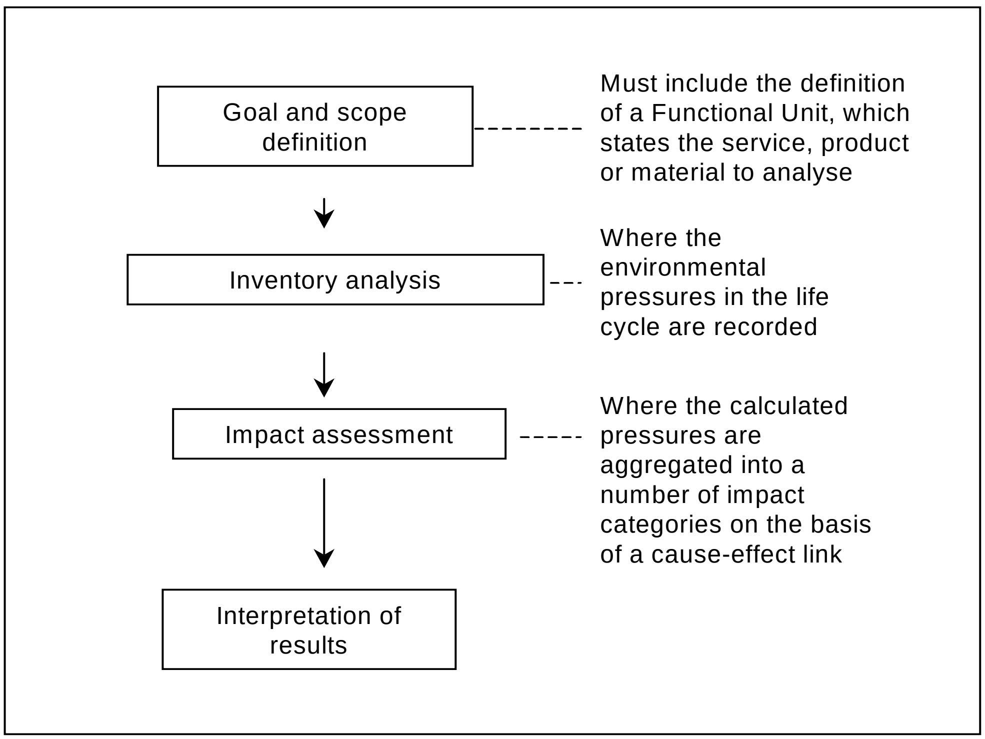


Figure 2.1 Illustration of the phases of an LCA

- Comparative LCA studies disclosed to the public must 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 goals of the study, so that the comparison is fair and equivalent for the product alternatives.
- Systems must be compared using the same functional unit and equivalent methodological considerations such as performance, system boundaries, data quality, decision rules and impact assessment.

- 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 LCA are scientifically and technically valid. For the inventory phase, the most important issue 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 selected by the review should fulfil the requirements indicated in the ISO 14040-series, but some studies carried out before the publication of the standard in 1997 have also been selected, after it was checked that the main principles required by the standard are followed. It is therefore important to highlight that the lack of fulfilment of the ISO standard has not been an exclusion criterion in this review.

2.1.3 Studies must be material-specific

Only studies which focused on the seven material streams in question were analysed. However, the type of product was not an exclusion criterion. For paper and cardboard, for instance, no LCA studies were excluded from consideration on the basis of the product types analysed. Likewise, LCA studies about glass in cars, hollow-fill containers or other components were all potential candidates, so long as the environmental impacts related to the material were analysed and reported on separately.

2.1.4 Studies must include a comparison of options at the end-of-life stage

To be relevant to this review, the study had to have included a comparison of one or more scenarios for the end-of-life waste management of the material stream in question.

Importantly, the life cycle of most recyclable materials is characterised by a number of secondary services, including:

- *Generation of energy*: combustible materials such as paper, wood and plastic have a heat value, which in scenarios including incineration can be transformed into heat and power. This energy, which is a product provided by the scenarios that include incineration, has to be provided as well by any scenario where the material is not incinerated but recycled or landfilled.
- *Use of energy for virgin and recycled material production:* in many LCAs, the geographical location of the production of virgin materials and the production of recycled materials is not the same, and therefore the origin of the energy used for production will also be different. This difference in the origin of energy can be very important in LCA studies, and it affects the magnitude of the impacts caused by any surplus or saving of energy registered in the systems compared.
- *Co-products:* some production processes result in the generation of co-products, such as slag from steel, bark from wood and paper, or petrochemical products from plastic manufacture. Any differences in production of such co-products have to be adjusted for when comparing options/scenarios.
- *Waste management systems*. A system with recycling does not place the same demands on waste disposal capacity (landfill/incineration) as a disposal system without recycling. A change in the use of the landfill and/or incineration capacity between two systems may have to be taken into account, depending on the availability of incineration/landfilling capacity in the region studied and the time-frame of the study.

- *Agronomic value*. If, in one of the systems, an organic residue is generated during the material's life cycle and is composted and used as fertiliser, then an equivalent supply of the same service has to be provided in the system with which it is being compared and has no residue generation.

Schematic illustrations of the life cycles of the seven materials are provided in **Appendix 4**, including the associated secondary services that occur within each system.

LCA studies of material recycling 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 being recycled. The loss in material grade that occurs determines the ratio at which recycled and recovered material can displace virgin material. While for example glass this may well be around 1:1, it is not better than 1:0.8 for any paper or cardboard category and can be lower for some plastics.

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

Some of the scenarios reviewed compared systems in which a mix of waste management options featured (e.g. a scenario comparing a 100% landfilling scenario versus a 60% recycling and 40% landfilling scenario). In scenarios where it was not possible to make the distinction between the contribution of the two management options separately, an individual exercise was undertaken to judge if the result of the comparison was significantly different from a comparison between unmixed systems. If the differences were not noticeable in the histogram, a 100% system has been assumed.

2.1.5 Time frame of LCA studies

The time span of the decisions supported by the LCA is not necessarily the same from a company perspective as from a societal perspective, because these studies have different goals and are designed to support different decisions.

It should be kept in mind what the decision to be supported by a study was, since it is the temporal and spatial outreach of the decision that influences how the boundaries were defined and how the time perspective was chosen. Short-term decisions (5-10 years) demand a rather different set of assumptions compared with longer-term strategic planning (10-20 years). This can influence, amongst other things, choice of relevant technologies (average vs. best available technology), the data quality, energy sources, environmental policies, the influence of the material's life cycle on other areas, the time horizon for the release of emissions (e.g. 20 years vs. 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 material production capacity, and it may imply for example that incineration of the material 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 different scenarios should be constructed to reflect different futures.

2.2 Short-listing of LCAs for detailed analysis

The complete list of all selected and rejected studies for each material is provided in **Appendix 3**. The most frequent reasons for rejection were:

- The study was a life-cycle study, but only covered a part of the life cycle of the material, e.g. cradle-to-grave inventories and/or inventory data for recycled materials that finish in the production of 1kg of the material. This group included very detailed and well documented life-cycle inventories which covered stages up to product manufacture, with no downstream processes included.
- The study was a full life-cycle assessment of a material-containing product, but there was no separate reporting of the impacts attributed to the material under scrutiny.
- The study was an LCA of the material including the whole life-cycle, but only examined a single end-of-life alternative, for example, there was no comparison of recycling versus incineration or landfilling, or it was not possible to identify what the difference between the scenarios was.
- The research was unavailable, despite repeated requests being made by the review team.

Some studies such as Grant et al. (2001), Plinke et al. (2000) and RDC and Pira (2003) fulfilled all criteria and provided comparisons of the whole life cycle of the material, including disposal options, but reported data in a form which could not be directly converted to the chosen percentages of increased/reduced impact, unless a simple calculation was made. Wherever possible, such calculations were carried out in order to adapt the data to the chosen percentage format.

2.3 Criteria used for the analysis of LCA studies

A number of key issues for the outcome of an LCA about disposal/recycling were identified. The key issues can be divided into three main categories:

- Assumptions regarding the interaction of the material production with the techno-sphere, including the system boundary delimitation in time and space, issues of system equivalence, identification of marginal technologies, marginal energy, and any secondary services.
- Impact assessment categories
- Data age and quality

2.3.1 Assumptions regarding interaction of the production system with the technosphere

A comparative LCA should, as far as possible, reflect the environmental consequences of 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 following from this is that the compared systems should be equivalent with respect to the goods and services they provide to society. If alternative A in an LCA scenario 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 impacts must be included in order to fully account for the environmental consequence of choosing A over B. If, for example, alternative A implies a supply of energy to the grid besides the supply of the material, 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 alternative A implies a change in demand of primary materials, the processes in the primary material system responding to the change in demand should be included, and only these. A primary material production taking place in Norway would, for example, draw its electricity from the Norwegian grid, which is 99% generated by hydro-electric schemes. A change in demand for electricity in Norway would, 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 would cause a change in the import or export of electricity with 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.

Identification of the correct marginal processes depends on the geographical scope and the time perspective of the study. Geographical scope and time perspective are, thus, not independent criteria, but form part of the issue of identifying the right marginals.

An overview of the identified essential system boundary criteria, for each life cycle stage of the materials is presented in **Tables 2.1** and **2.2**.

Table 2.1 Key system boundary issues in LCAs of recycled materials excluding paper and cardboard. Issues are numbered for comparison with material system diagrams in Appendix 4

Material production	Virgin material	
	1	Material marginal. Average or specific? Which?
	2	Electricity marginal: which? Hydro, biomass, coal, gas, oil, other?
	3	Steam marginal: which? Biomass, coal, gas, oil, other?
	4	Co-products dealt with? If Yes: By allocation? By system expansion?
	Secondary material	
	5	Material marginal. Average or specific? Which?
	6	Electricity marginal: which? Hydro, biomass, coal, gas, oil, other?
	7	Steam marginal: which? Biomass, coal, gas, oil, other?
	8	Co-products dealt with? If Yes: By allocation? By system expansion?
Ante - material recovery	9	Product dependent material recovery included? Yes/no
	10	Type of product dependent material recovery
Material disposal	11	Disposal comparison e.g.: recycling vs. incineration
	12	Emissions from landfill included? Considered/no information
	13	Energy from incineration substitutes heat? Considered/no information
	14	Energy from incineration substitutes electricity? Considered/no information
	15	Alternative use of incineration capacity included? Considered/no information
	16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other) Ratio

Table 2.2 Key system boundary issues in the LCA of paper and cardboard. Issues are numbered for comparison with material system diagrams in Appendix 4

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 & landfilling 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?

The location of the issues in **Tables 2.1** and **2.3** within each material system is illustrated within the material systems diagrams in **Appendix 4**.

In LCAs, different assumptions are made in order to account for the energy recovery potential, with energy recovery differentiated between electricity and heat production. Moreover, electricity and heat from incineration plants can substitute electricity and district heating on the public grid to a varying degree, depending on the geographical location and time of the year. These issues are highly important to identify and get right. They are illustrated in positions 13 and 14 in the non-paper/cardboard systems diagrams shown in **Appendix 4** (excluding aggregates where this aspect is not relevant) and in positions 11 and 12 for paper/cardboard. When material recycling is performed at the expense of incineration/landfilling, a certain amount of capacity at these facilities will be released for other purposes. For example, in the short term this may imply the use of the released 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 positions 15 (non-paper/cardboard systems excluding aggregates) and 13 (paper/cardboard) in the **Appendix 4** diagrams.

2.3.1 Impact assessment categories

Table 2.3 illustrates the impact categories for the environmental assessment of material systems used in this review, representing the scope of inputs contained in the analysed LCAs.

Table 2.3 Environmental impact categories used for the assessment of material systems

Energy use/generation
Resource consumption
Global warming potential
Other energy-related impacts (acidification potential, nutrient enrichment potential, photochemical ozone formation potential)
Toxicity potentials
Waste generation
Other – e.g. land use, stratospheric ozone depletion potential

The energy consumption of the material systems is probably one of the most significant single sources of environmental impact (European Commission, 2001). Almost all LCAs analysed included this category, and most of them also included specific accounts for the energy balance of the systems or for impacts related to energy.

Due to the geographical differences in the fuel type used and in the energy marginals, it is also necessary to supplement the energy accounting by a translation into the energy-related environmental impacts. The main impact categories involved are global warming potential (CO_2 equivalent), acidification potential, nutrient enrichment potential and the potential to form photochemical ozone.

In general the significance of transport impacts within material life cycles appears to be very small. Among the LCA studies analysed, Tillman *et al.* (1991) indicated that the transport contribution to the overall energy profile was insignificant. In Craighill *et al.* (1996) the percentage was 1% and in Grant *et al.* (2001) it was less than 1%. Most of the LCA studies analysed assumed collection systems based on mixed waste sorting, bring sites, or special containers to collect waste from industrial and commercial premises.

There were exceptions to this finding that related to extreme cases where scenarios were constructed with very high transportation requirements (RDC Environment and Coopers & Lybrand, 1997). Furthermore, transport emissions can contribute disproportionately to specific emissions, such as carbon monoxide, NO_x, or hydrocarbons emissions, where its contribution can be up to 75% of the total. However, the contribution of these emissions to the associated environmental impacts was in most cases less than 5% (Tillman *et al.*, 1991).

2.3.2 Data age and quality

Most LCA studies have been carried out in the period 1991 to 2005. It was not until the mid 1990's that the first methodological articles describing key issues in material recycling LCAs were published (e.g. Amato *et al.,* 1996, or Ekvall, 1996). It is most likely that the results of the studies published before 1995 did not considered key methodological questions involved in recycling LCA, and therefore their results should be treated with caution.

Of the 55 studies reviewed, 14 were pre-1997, when the ISO 14040 methodology was first published and only 6 were of pre-1995 vintage.

3. Results

3.1 Introduction

Throughout this section results have been presented by material and impact category for each of the three main categories of end-of-life comparisons:

1) Scenarios that compared recycling to incineration
2) Scenarios that compared recycling to landfill
3) Scenarios that compared incineration to landfill

With the exception of paper/cardboard, results have been reported separately under each of these three headings. For paper and cardboard, where results were more complex for the comparison of recycling versus incineration, particular attention has been given to four key system issues that were found to be decisive to determining the outcome of this comparison.

All the supporting details and the background for results can be consulted in **Appendix 5** which contains the summary matrices for each of the scenarios contained within the 55 studies.

The results from the comparison of each pair of waste management options have been presented graphically in terms of the relative difference between the options being compared. For example, for comparison between recycling and incineration, the relative difference calculation was as follows:

$$\frac{[\text{Impact from recycling}] - [\text{Impact from incineration}]}{[\text{Impact from incineration}]}$$

In order to explore the relative environmental benefits across the range of scenarios reviewed, each scenario was represented by a numbered box, the first digit indicating the number of the study and second, the scenario within it (see **Appendix 5**). These were then placed along a scale of relative environmental burden, indicating which option had either more or less environmental burden than the other. For example, the value for the parameter 'energy consumption' from glass scenario 5.1 is -62% (see **Appendix 5**, Glass Study 5, scenario 1), and was thus placed in the interval between -75% and -50% on the scale. A negative value on the scale suggested that the results for recycling caused less environmental impact than incineration, and values further to the left indicated greater reductions compared with incineration. For the comparison of incineration versus landfilling, the relation of course went between incineration and landfilling instead. If one scenario came up with a value within the same range as another, the boxes were then stacked in columns, producing a frequency distribution of results across the entire review for that particular material, impact category and waste management comparison.

Some of the reviewed studies only covered part of the life cycle, and could not therefore be included in the same stacks as whole life cycle scenarios. Such cases were placed off the scale of the graphs as a qualitative indication of the relative environmental impact of the comparison covered by the scenario. These were indicated by boxes with dashed outlines off the scale on either the left or right hand side of the diagram, depending on the environmental preference.

3.2 Paper and cardboard

3.2.1 Main findings

Results from the 9 comparative LCAs that were selected for detailed analysis, comprising 68 scenarios, were examined for their overall environmental preference. The main features of these studies and the preferred environmental option from each comparison is summarised in **Table 3.1**, with more detailed descriptions in **Appendices 3** and **5**.

The review found that in practically all studies for paper and cardboard, recycling was environmentally preferable to landfilling and to the prevailing mix of incineration and landfilling (around 20-30% incineration and 70-80% landfilling in the countries covered by the studies). Only one scenario comparing incineration with landfilling was identified, and showed a clear preference for incineration.

The comparison between paper/cardboard recycling and incineration was more varied. Within some impact categories, recycling was found by the majority of studies to lead to a reduction in environmental burden. This was the case for:

- overall energy consumption,
- energy related impacts of acidification, nutrient enrichment and photochemical ozone formation,
- toxicity, and
- other impacts (COD in wastewater effluents and land use)

Within the other impact categories (consumption of fossil fuels, global warming and solid waste), the results of the reviewed studies were distributed more evenly between advantages and disadvantages for both recycling and incineration.

Table 3.1 Summary of Paper and Cardboard LCAs reviewed

Study no.	Country/ region	Type of paper/ cardboard sudied	Scen. no.	Waste management comparison	Predominant environmental preference			
					Recycl.	**Incin.**	**Landf.**	**Inc/land mix**
1	Sweden	Corrugated board	1.1	Recycling vs. landfill	X			
			1.2	Recycling vs. incineration		X		
		Paper board	1.3	Recycling vs. landfill	X			
			1.4	Recycling vs. incineration		X		
2	Denmark	Corrugated board	2.1	Recycling vs. incineration	(X)	X		
			2.2	Recycling vs. landfill	X			
			2.3	Recycling vs. incineration	X			
			2.4	Recycling vs. landfill	X			
		Newspapers and magazines	2.5	Recycling vs. incineration	X			
			2.6	Recycling vs. an inc./landfill mix	X			
			2.7	Recycling vs. incineration	X			
			2.8	Recycling vs. an inc./landfill mix	X			
		Mixed paper	2.9	Recycling vs. incineration	(X)	X		
			2.10	Recycling vs. an inc./landfill mix	X			
			2.11	Recycling vs. incineration	X			
			2.12	Recycling vs. an inc./landfill mix	X			
3	AU, SF, F, I, NL, S, UK and D	Mixture of newsprint, writing paper and board	3.1	Recycling vs. incineration	X			
4	Germany and Finland	Newsprint	4.1	Recycling vs. incineration		X		
		Magazines	4.2	Recycling vs. incineration		X		
5	UK	Newspapers and magazines	5.1	Recycling vs. incineration	X			
6	Australia	Newsprint	6.1	Recycling vs. landfill	X			
			6.2	Recycling vs. landfill	X		X	
		Cardboard packaging	6.3	Recycling vs. landfill	X			
			6.4	Recycling vs. landfill	X			
7	Germany	Graphic paper	7.1	Recycling vs. an inc./landfill mix	X			
			7.2	Recycling vs. an inc./landfill mix	X			
			7.3	Incineration vs. landfill		X		
			7.4	Recycling vs. incineration	X	X		
			7.5	Recycling vs. incineration	X			
			7.6	Recycling vs. incineration	X			
8	USA	Newsprint	8.1	Recycling vs. landfill	X			
			8.2	Recycling vs. incineration	X			
			8.3	Recycling vs. an inc./landfill mix	X			
		Corrugated board	8.4	Recycling vs. landfill	X			
			8.5	Recycling vs. incineration		X		
			8.6	Recycling vs. an inc./landfill mix	X			
		CUK paperboard	8.7	Recycling vs. landfill	X			
			8.8	Recycling vs. incineration		X		
			8.9	Recycling vs. an inc./landfill mix	X			
		SBS paperboard	8.10	Recycling vs. landfill	X			
			8.11	Recycling vs. incineration	X	X		
			8.12	Recycling vs. an inc./landfill mix	X			
		Office paper	8.13	Recycling vs. landfill	X			
			8.14	Recycling vs. incineration	(X)	X		
			8.15	Recycling vs. an inc./landfill mix	X			
9	Denmark	Mixed paper	9.1	Recycling vs. incineration	X	X		
			9.2	Recycling vs. incineration	X			
			9.3	Recycling vs. incineration	X	X		
		Newspapers and magazines	9.4	Recycling vs. incineration	X			
			9.5	Recycling vs. incineration	X			
			9.6	Recycling vs. incineration	X			
		Corrugated board	9.7	Recycling vs. incineration		X		
			9.8	Recycling vs. incineration	X			
			9.9	Recycling vs. incineration		X		
		Mixed paper	9.10	Recycling vs. incineration	X			
			9.11	Recycling vs. incineration	X			
			9.12	Recycling vs. incineration	X			
		Newspapers and magazines	9.13	Recycling vs. incineration	X			
			9.14	Recycling vs. incineration	X			
			9.15	Recycling vs. incineration	X			
		Corrugated board	9.16	Recycling vs. incineration	X			
			9.17	Recycling vs. incineration	X			
			9.18	Recycling vs. incineration	X			

In all, the 15 essential boundary issues and assumptions discussed in Section 2 for paper and cardboard LCAs (**Table 2.2**), were in most cases dealt with by the reviewed studies, with some exceptions. **Table 3.2** presents an overview of the handling of these system boundary conditions and the extent to which the studies explicitly addressed them.

Table 3.2 Overview of the extent to which the 15 key system boundary issues were considered in the LCA studies analysed

Code	**System boundary conditions**		**Number of studies**	**% of the studies that consider the given boundary condition**
1	Alternative use of land/wood considered?	Considered	3	33%
		n.i.	6	-
2	Saved wood used for energy considered?	Considered	3	33%
		n.i.	6	-
3	Wood marginal considered?	Considered	3	33%
		n.i.	6	-
4	Virgin paper - Electricity marginal considered?	Considered	9	100%
		n.i...	0	-
5	- Steam marginal considered?	Considered	8	89%
		n.i.	1	-
6	Recovered paper - Electricity marginal considered?	Considered	8	89%
		n.i.	1	-
7	- Steam marginal considered?	Considered	6	67%
		n.i.	3	-
8	Energy export from virgin paper considered?	Considered	3	33%
		n.i.	6	-
10	Emissions from landfill considered?	Considered	7	78%
		n.i.	2	-
11	Energy from incineration substitutes heat- considered?	Considered	5	56%
		n.i.	4	-
12	Energy from incineration substitutes electricity – considered?	Considered	7	78%
		n.i.	2	-
13	Alternative use of incineration /landfilling capacity considered?	Considered	3	33%
		n.i.	6	-
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	-
15	De-inking sludge considered?	Considered	6	67%
		n.i.	3	-

n.i. = no information

Issues 1-3 deal with the system boundaries of the consumption of land and wood (see **Appendix 5** systems diagram). Three of the nine studies included scenarios in which the wood saved as a result of paper/cardboard being recycled was used for energy purposes. In one study (Frees *et al.,* 2004), the reasoning was that such scenarios represented a future in which biomass might be considered a priority energy fuel of limited availability, implying that the marginal resource of wood would be the same as the marginal fuel within the energy system of society in general (i.e. some kind of fossil fuel). In plain language it means that in such a future scenario, any use of wood would deprive society of the possibility of using it in the energy sector and would imply an equivalent use of fossil fuels in the energy sector to compensate. The two other studies (Dalager *et al.,* 1995 and Environmental Defense, 2002) did not consider whether or not biomass would become limited, the aim of including alternative uses for wood in these studies was merely to compare the environmental consequences of the options for the use of wood that society has. The remaining six studies did not consider the issue, and implicitly – without any formulated awareness of it – these studies assumed that wood/biomass in the studied future would be of unlimited availability and that society would not incurr any opportunity costs in using wood for virgin paper/cardboard production. This issue was found to be decisive to the results and conclusions of any LCA on paper and cardboard, and its significance has been elaborated in a further discussion of the results.

Issues 4-8 deal with the assumptions on the energy systems of paper/cardboard production. Issues 4-7 relate to the energy consumption during production itself, and the studies were typically fully transparent in stating the assumptions made on this issue. Some of the studies, however, did not comply with best LCA practice in the sense that they did not consider nor include the correct energy marginal, maybe because they were conducted before the issue of marginal systems had penetrated the scientific discussions around LCAs. This issue was also found to be highly significant for study results and conclusions, as illustrated in the breakdown of results presented later in this section. Issue 8 represents the point at which some virgin paper/cardboard mills have excess energy that can be supplied to the grid. This is probably only the case for corrugated cardboard production, and the fact that only 33% of the studies considered this issue was, therefore, not an indication of the lack of awareness of the issue, but merely a function of which paper/cardboard type was being studied.

Issues 10-15 deal with the system boundaries surrounding paper/cardboard disposal. Issue 9 has been omitted from Table 3.2, because it is the issue on which waste disposal scenarios have been compared, and all of the selected studies were fully transparent on this aspect. Most studies included landfill emissions (issue 10), although with different levels of detail. However, only a third of studies considered changes in waste flows resulting from changes in demand for incineration/landfilling capacity (issue 13). For example, what happened to the incineration capacity released as a consequence of paper/cardboard recycling ~ was it used to take in more waste from landfills and was this accounted for? Whether such a system boundary should in fact be included or not depends on the available incineration capacity and state of waste management in the studied country/region and on whether or not the study assessed options in the short or long term. Most studies were well aware of considering any energy substitution from waste incineration at plants with energy recovery (issues 11 and 12). The fact that only 56% of the studies considered utilisation of heat from incinerators, whereas 78% consider electricity production, probably just reflected the fact that many incinerators only produce electricity and do not supply waste heat to district heating or other applications. Only half of the studies justified the substitution ratio between recycled and virgin paper/cardboard (issue 14), and the remaining studies probably anticipated a substitution of 1:1 without categorically stating the fact. The latter is an over-sight, as a substitution ratio should not be assumed above 1:0.8 (as discussed in **Appendix 4**). Finally, 67% of the studies were judged to be transparent about the fate of de-inking sludges, but this issue was found to be of minor overall significance within the LCAs reviewed.

The studies which contained the most scenarios were Dalager *et al.* 1995 (18 scenarios), Environmental Defence 2002 (15 scenarios) and Frees *et al.* 2004 (18 scenarios). Tiedemann *et al.* (2001) also included numerous scenarios, but a selection of 6 of these scenarios was included, based on their relevance to the present study. The LCA studies mentioned were amongst the most complete ones regarding the inclusion of the key assumptions. This relationship was a logical one, 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 on that key assumption.

All of the 15 issues were, as previously stated, important to the result and conclusion. Some of them, however, turned out to be more so than others. During the analysis of the results of the reviewed studies, the most significant issues and assumptions have been identified, and an analysis of their influence on the results is been presented below.

The overall results, summarised in **Figures 3.1–3.5**, suggested that recycling paper and cardboard is environmentally preferable to landfilling and to the prevailing mix of incineration and landfilling in the studies (around 20-30% incineration and 70-80% landfilling). The one scenario comparing incineration to landfilling, moreover, showed a clear preference for incineration. However, the overall picture from the comparison between recycling and incineration was more varied, and a closer analysis showed that results and conclusions were dependent on key assumptions, and especially four issues that were found to be decisive, namely:

1. The energy split between electricity and thermal energy in production of the various virgin paper and cardboard types.

2. The marginal electricity assumed for virgin paper/cardboard production

3. The potential utilisation of the extra incineration capacity created by recycling to reduce landfilling

4. The inclusion of an opportunity cost of using wood for virgin paper/cardboard production

The cause-effect relationships between assumptions on these issues and LCA outcomes have been analysed here in detail. They exist, of course, also for the other waste management option comparisons, but not to the extent that changes in assumptions can reverse conclusions, as they can for the recycling versus incineration comparison. In order to analyse this linkage between results/conclusions and system boundary assumptions, the recycling versus incineration comparisons have been examined more closely.

As **Figures 3.1-3.5** illustrate, there were clear differences between results within the various impact categories: some categories show a clear preference for recycling, whereas others show a more even distribution. The underlying reasons for this are explained in the following.

Energy consumption: There is an unambiguous conclusion that total energy consumption was less from recycling than from incineration of paper and cardboard. In fact, the distribution of the results from all scenarios in the reviewed studies showed a normal distribution with an average difference of 50%. In other words a 50% overall energy saving was implied when recycling paper and cardboard instead of incinerating it.

This finding accords well with the technical aspects of the paper/cardboard system. When making virgin paper and cardboard, it is necessary to refine the wood, and that requires energy. For most paper/cardboard grades, the refining implies an extraction of the cellulose fibre, which constitutes only around 50% of the dry matter content of the wood. The process energy used for the refining can, thus, be equal to or higher than the residual heat value of the paper/cardboard. When incinerating the paper/cardboard, only the heat value can, of course, be recovered, and moreover this energy recovery in waste incinerators typically has a somewhat lower efficiency than for the conventional energy supply to the heat and electricity grids. For recycling, however, both process energy and heat value of the virgin paper is avoided, of course at the cost of the energy consumption of the paper recycling. The basic understanding of these technical energy aspects shows, as a rule of thumb, that on average: virgin paper production followed by incineration with energy recovery consumes twice as much energy as paper recycling.

An important acknowledgement is, moreover, that the energy systems dominate the results of environmental comparison between waste management options. Some years back, wastewater effluents from virgin paper production were environmentally more significant, but wastewater treatment and changes towards more environmentally benign chemicals in e.g. bleaching, have reduced the significance of wastewater effluents. Today environmental impacts from the underlying energy systems dominate the environmental aspects of paper making.

The only reason that the conclusion on energy consumption did not repeat itself in the energy related impact categories was that the energy systems behind virgin paper/cardboard production were not the same as the ones behind recovered paper/cardboard: the sources of energy are different. Most of the disparities between results and conclusions from the various studies and scenarios can be derived from different ways of handling these differences in underlying energy systems and fuels.

Resource consumption: this impact category comprises essentially the fossil fuels of the systems, and it directly reflects the above mentioned issue of the differences in underlying energy systems. Whereas virgin paper/cardboard mills for most paper/cardboard categories to a large extent use wood and/or hydropower as the primary underlying energy source, paper/cardboard recovery mills typically use fossil fuels only.

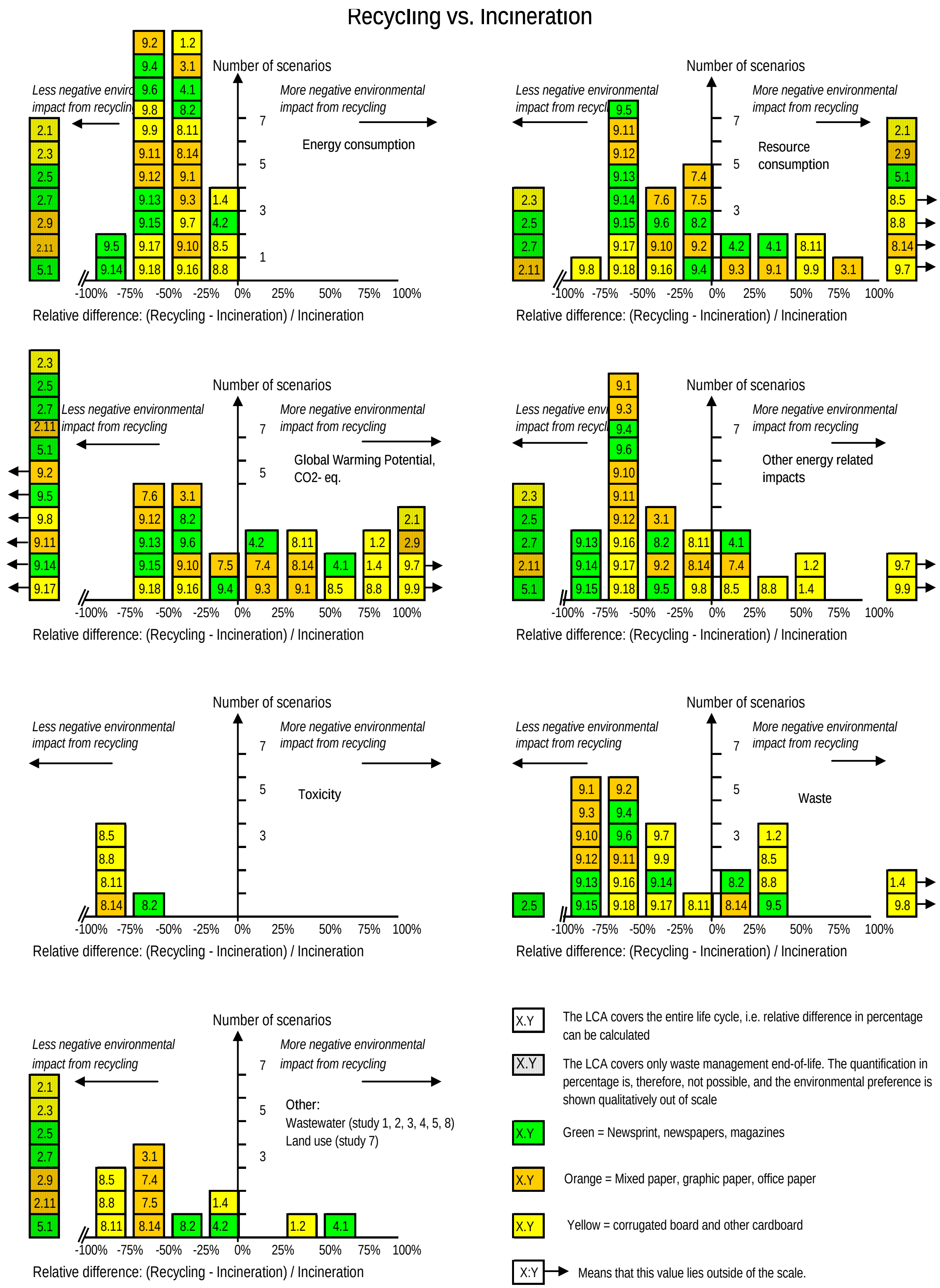


Figure 3.1 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. incineration. A negative value means that recycling causes less impact than incineration

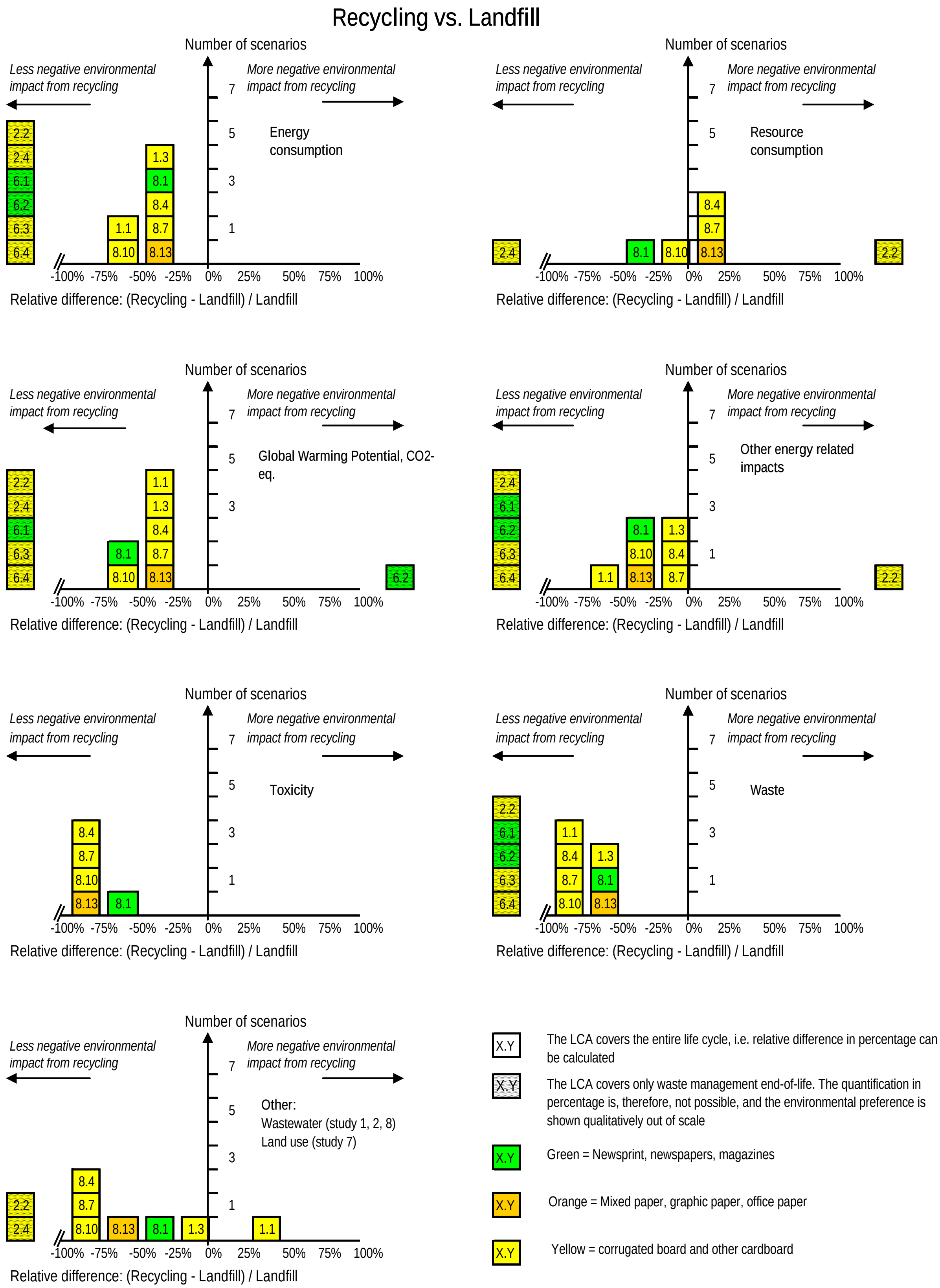


Figure 3.2 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. landfilling. A negative value means that recycling causes less impact than landfilling

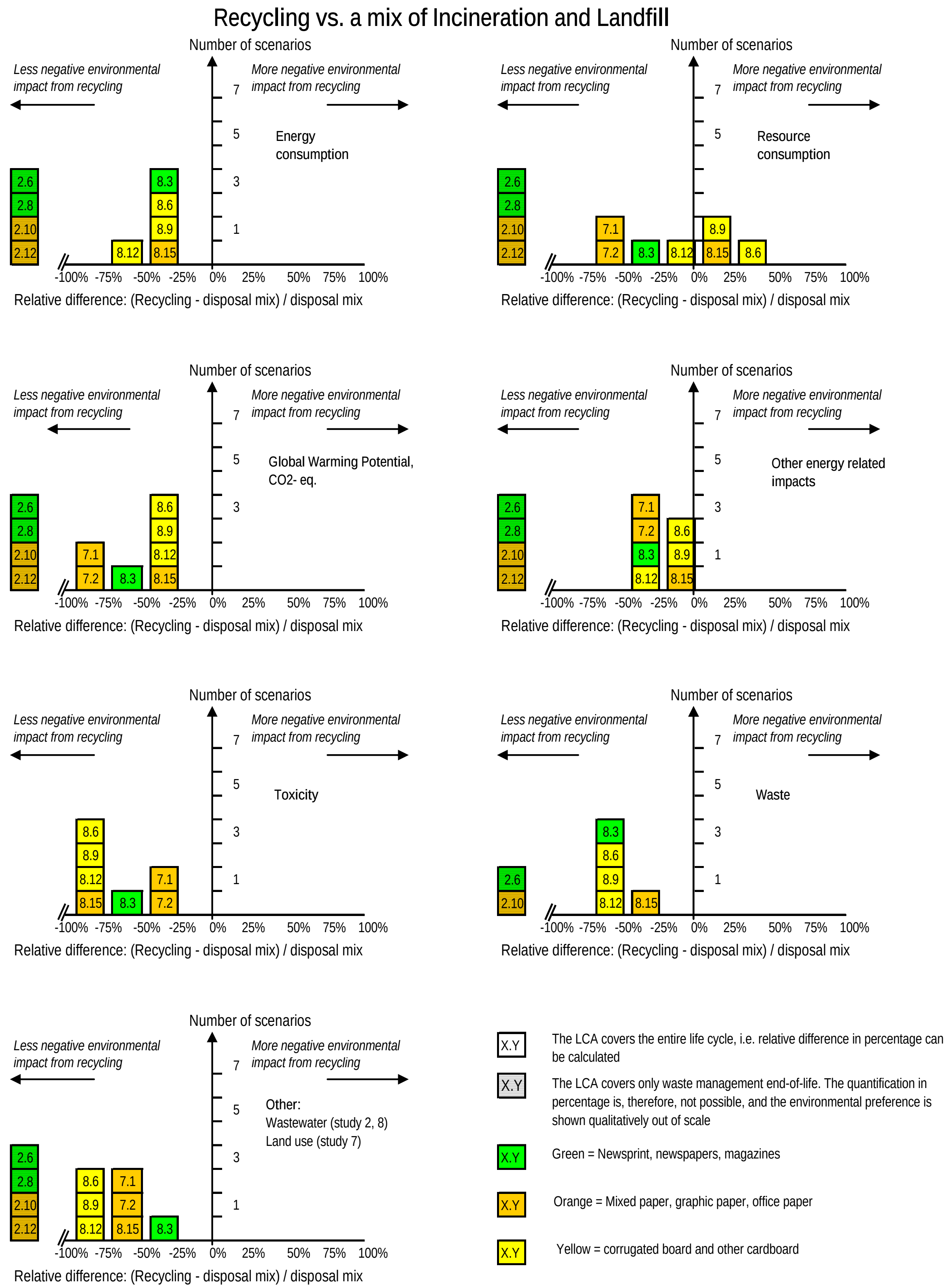


Figure 3.3 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. a mix of incineration and landfill. A negative value means that recycling causes less impact than this disposal mix

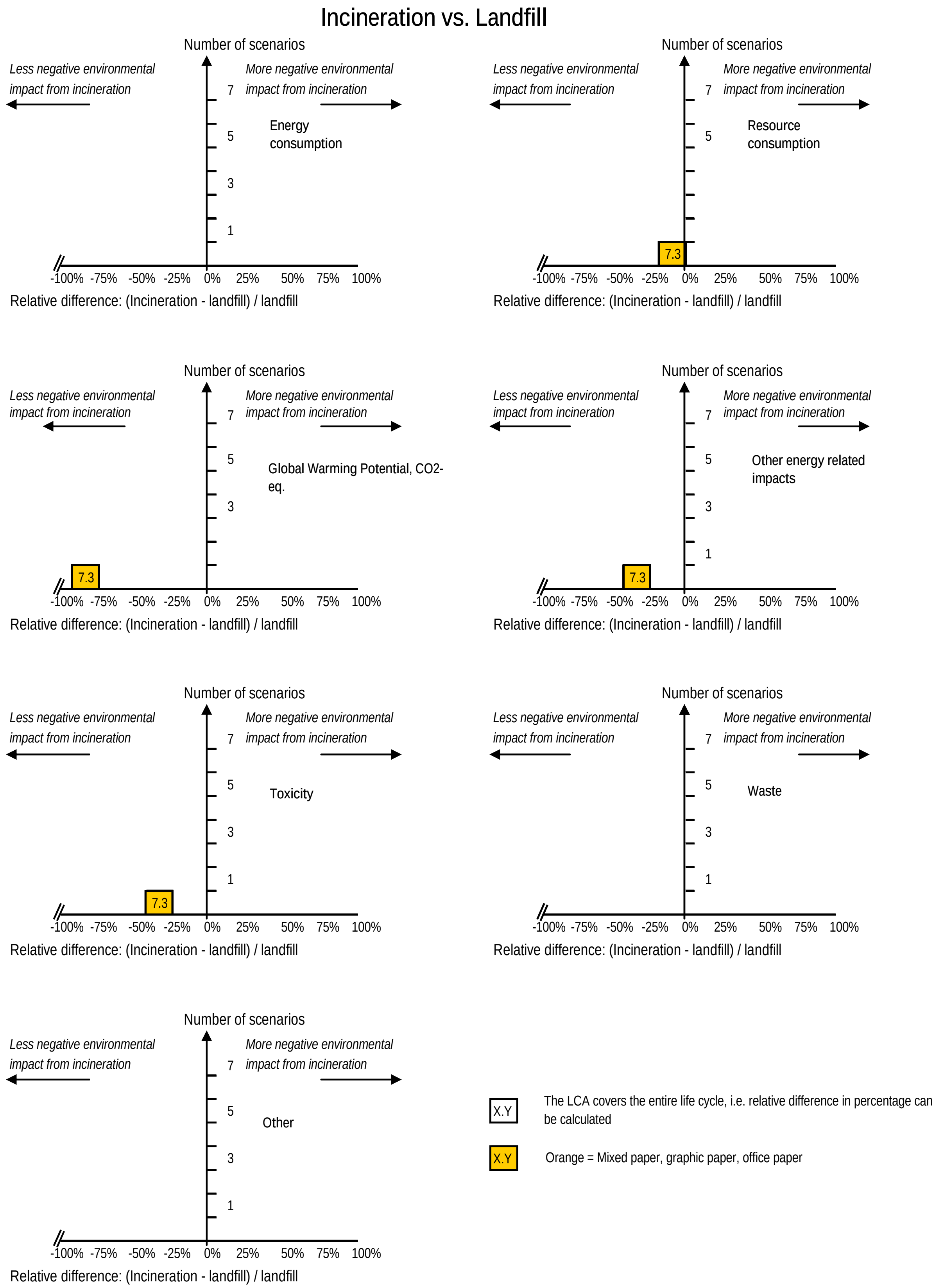


Figure 3.4 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from incineration vs. landfill. A negative value means that incineration causes less impact than landfilling

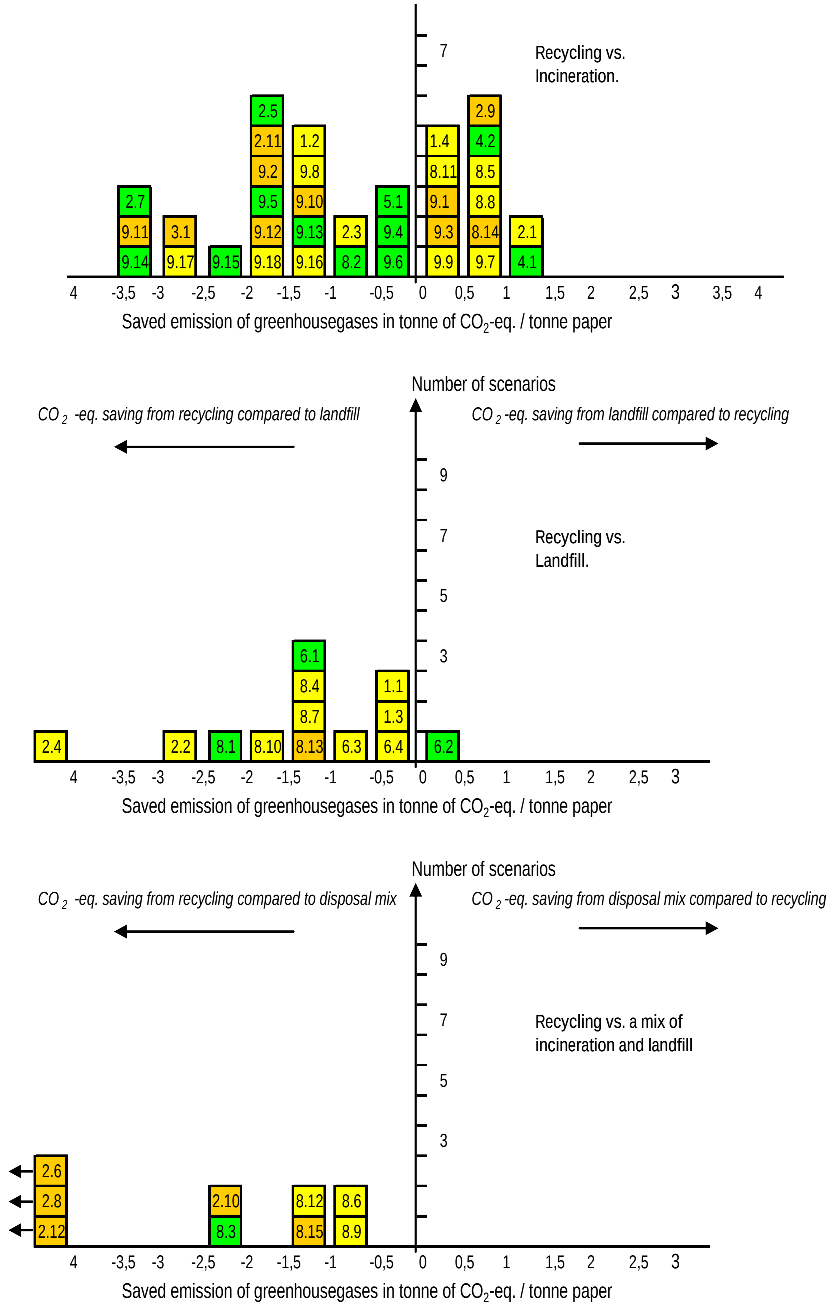


Figure 3.5 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the saved emission of greenhouse gases from recycling vs. incineration and recycling vs. landfill respectively. A negative value (the left side of the diagrams) means that recycling causes a saving compared to incineration or landfill. For legends: see Ffgure 3.1

Global warming: the point mentioned under resource consumption is exactly the same for global warming, as the main contributor to global warming is CO_2 from the energy system. Some contribution comes from CH_4 from anaerobic degradation at landfills in scenarios comprising landfilling, but this is not significant in the recycling versus incineration comparisons. For both resource consumption and global warming, the energy system boundary assumptions are, thus, crucial for the results and conclusions and of highest importance to get right, and all of the 4 above mentioned decisive issues relate to this. The identified variation of results on resource consumption (i.e. fossil fuel consumption) and global warming was, therefore, *not* an indication of a general uncertainty of the environmental preference between paper/cardboard recycling versus incineration, on the contrary, the differences were due to:

a. *either* inherent differences within the energy system of the type of paper/cardboard studied (issue 1 of the above mentioned 4 key issues)
b. *or* choices of energy system boundary conditions correctly or incorrectly taken within the study in question (issue 2 – 4 of the above mentioned 4 key issues)

In all cases differences can be explained and traced back to these issues. This is illustrated in **Sections 3.3.2 -3.3.5**, each dealing with one of the four key issues.

Other energy related impacts: the other energy related impacts are acidification (deriving mainly from emission of SO_2 and NO_x), nutrient enrichment (deriving mainly from NO_x emission), and photochemical ozone formation (deriving mainly from emission of hydrocarbons). On these impact categories, an overall preference of recycling was found, and the results did not show the same distribution as resource consumption (of fossil fuels) or global warming (CO_2). The reason was that the SO_2 emission is to a great extent correlated with the sulphur content of the fossil fuels utilised and for this part it follows the same distribution as fossil fuel consumption and CO_2. But some paper/cardboard qualities contain a lot of sulphate, some of which can be found in emissions released during incineration. Moreover, the emission of NO_x and hydrocarbons is not correlated in any simple way to fossil fuels. NO_x is generated from nitrogen in the combustion air, and the incineration conditions determine the NO_x formation. In fact, NO_x formation was more often higher from incineration of biomass than from fossil fuel combustion.

Toxicity: Only two studies (Tiedemann *et al.,* 2001 and Environmental Defence, 2002) included data on toxicity/toxic substances, and in all scenarios from these studies, there was a clear preference of recycling on this impact category. It should be mentioned that there was no evidence that the data on toxic substances in any way were exhaustive in their coverage of toxic air emissions and waste water effluents from the studied systems.

Waste: waste derives both from the energy systems and the paper/cardboard disposal and recovery. The main contributors were slag and ashes from power plants and from incineration of paper/cardboard (many paper/cardboard types contain a lot of inorganic filler). This impact category gave a varied picture, because coal-based power plants were represented to a larger extent in the scenarios, whereas paper/cardboard incineration naturally was represented more in the incineration scenarios.

Other impacts: the main groups of other impacts found in the reviewed studies were wastewater effluents (non-toxic constituents represented by COD and nutrients, as toxic substances/toxicity has already been discussed) and land use impacts. These impact categories showed a clear preference of recycling. It is well known that wastewater COD effluents are much higher from virgin paper/cardboard production than from recovery processes, and likewise it is evident that the use of forest land is much higher for virgin. The impact of land use was included in one study only (Tiedemann *et al.,* 2001), and its effect on the availability of natural land and biodiversity was discussed and given very high priority in this particular study.

As evident, the impact categories of resource consumption (fossil fuels) and global warming were the ones giving rise to the most unambiguous conclusions, and they were good indicators of the significance of the above mentioned 4 decisive issues. Moreover, they were highly correlated with one another. For this reason the global warming was chosen as the indicator when analysing the cause-effect relationships between system boundary assumptions on the 4 issues and the consequential results and conclusions.

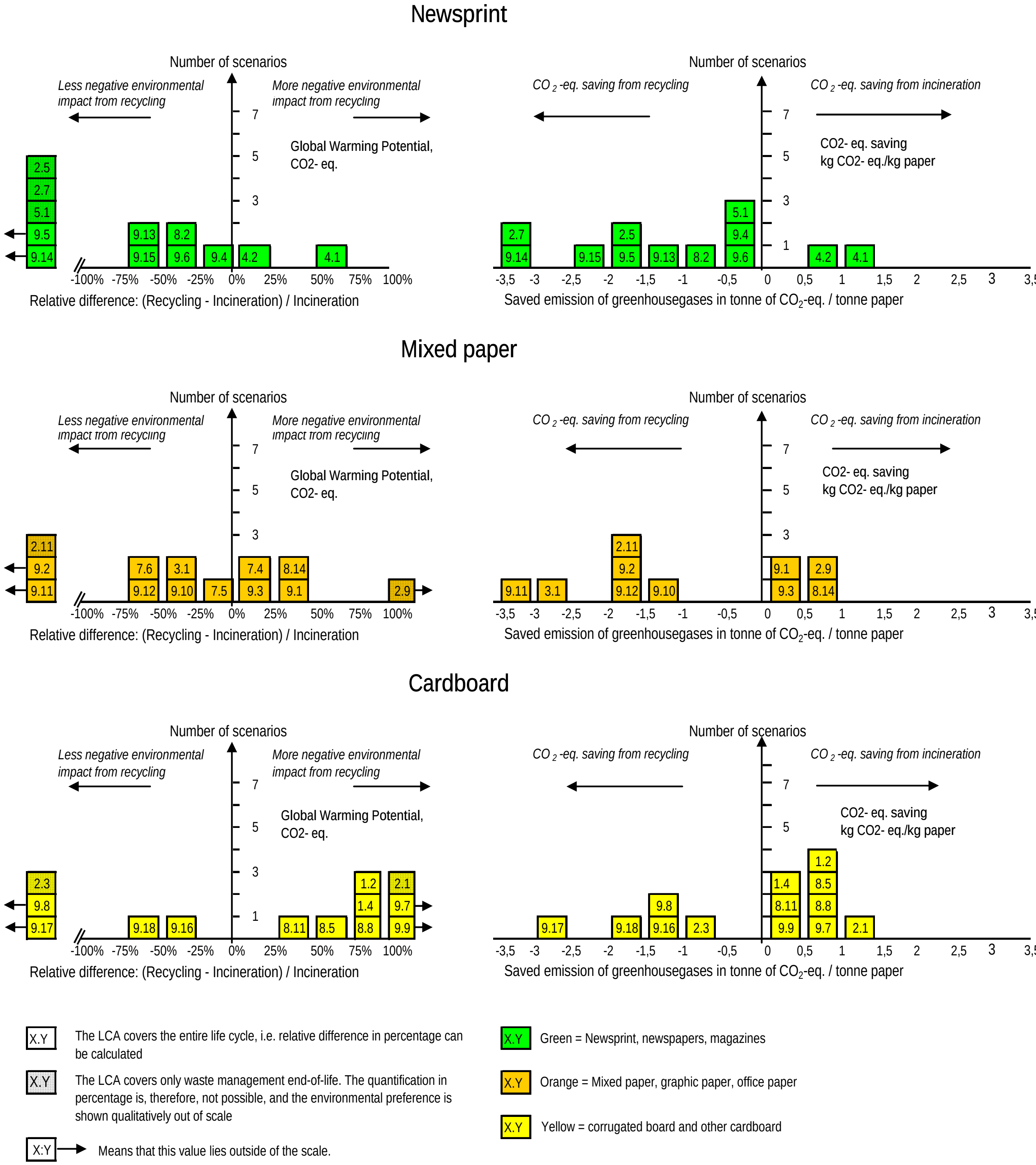
3.3.2 The energy split between electricity and thermal energy in virgin paper and cardboard production

Some virgin paper/cardboard qualities are produced in mills predominantly using electricity, whereas thermal energy, in the form of steam, is the main source of energy in others. The main difference lies between thermo-mechanical-pulp (TMP) and chemical-thermo-mechanical-pulp (CTMP), using mainly electricity in the production, in contrast to craft pulp (sulphate pulp) using mainly thermal energy (steam) produced from wood.

The paper category called ‘newsprint’ consists of newspapers and magazines, and newspapers are produced from TMP and CTMP only whereas magazines are made of both TMP/CTMP and some craft pulp. On average, this paper type is characterised by a high content of TMP/CTMP and, thus, a high degree of electricity is used in the energy systems of virgin paper production. At the other end if the spectrum lie virgin corrugated cardboard and other virgin cardboard ~ being based solely on craft pulp. In between these paper/cardboard categories lies the category of ‘mixed paper’ including in this overview also ‘office paper’ representing probably a mix of all pulp types.

In **Figure 3.6**, results have been divided between the different paper/cardboard categories to illustrate the significance of the predominant energy splits in virgin paper production. The overall distribution of results for newsprint predominantly showed an environmental preference of recycling, mixed paper showed an almost equal preference whereas cardboard showed a predominant preference of incineration. The explanation is that the higher overall energy consumption exerts its influence on CO_2 – emissions in virgin newsprint production, being based on electricity and emissions from the electricity production on the grid in general, whereas the thermal energy in the virgin cardboard production in most scenarios was assumed to be based on CO_2 – neutral fuels (wood). But the frequency histograms in **Figure 3.6** do not reflect a homogenous population of data for each paper/cardboard category either, because essential differences in assumptions within each category still exist, as considered in the next sections.

Figure 3.6.



Recycling versus incineration ~segregation of results on global warming impacts in frequency histograms for each the main paper/cardboard categories

3.3.3 The marginal electricity

As previously discussed, data and results from an LCA should reflect the consequence of choosing one alternative over the other. One of the requirements to fulfil this criterion is that the included processes and systems are the ones responding to a change in demand (the marginal ones).

This issue is highly significant, because virgin paper/cardboard production is often located in countries in which there is much CO_2 – free or CO_2 neutral electricity in the average electricity production on the grid, i.e. hydropower, biomass/wood and nuclear power.However, these are usually not the marginal sources of electricity, on the contrary the marginal source is more often a fossil fuel based electricity in the same or a neighbouring country.

Some of the studies have assumed an electricity production being partly or fully based on wood. Without having the details allowing an accurate judgement as to whether this was wrong for the region studied, it is safe to say, the there is a high probability that it was.

In **Figure 3.7** scenarios assuming wood-based electricity have been segregated from the rest. It is evident that this assumption clearly favoured incineration, i.e. almost all scenarios that assumed wood-based electricity for virgin paper/cardboard production showed lower CO_2 – emissions from incineration – with only two exceptions, namely scenario 3.1 and 5.1. In scenario 3.1, however, the main contributor to global warming from the incineration scenario was an assumed formation of methane derived from the anaerobic degradation of non-harvested wood waste remaining in the forest and caused by the extra demand for wood in the incineration scenario. This scenario was the only one assuming such increased wood waste residues (compared to 'natural forests') caused by the extra wood demand for virgin paper production. By eliminating this methane formation in scenario 3.1, one gets the results represented by the scenario called 3.1' in the Figure. Only scenario 5.1 then remains in favour of recycling when assuming wood-based electricity, so the issue of choosing the right marginal electricity for virgin paper/cardboard production is highly significant.

Note also, that no scenarios studying newsprint found less global warming from incineration unless electricity was assumed to be partly or fully based on wood (or another CO_2 – neutral fuel).

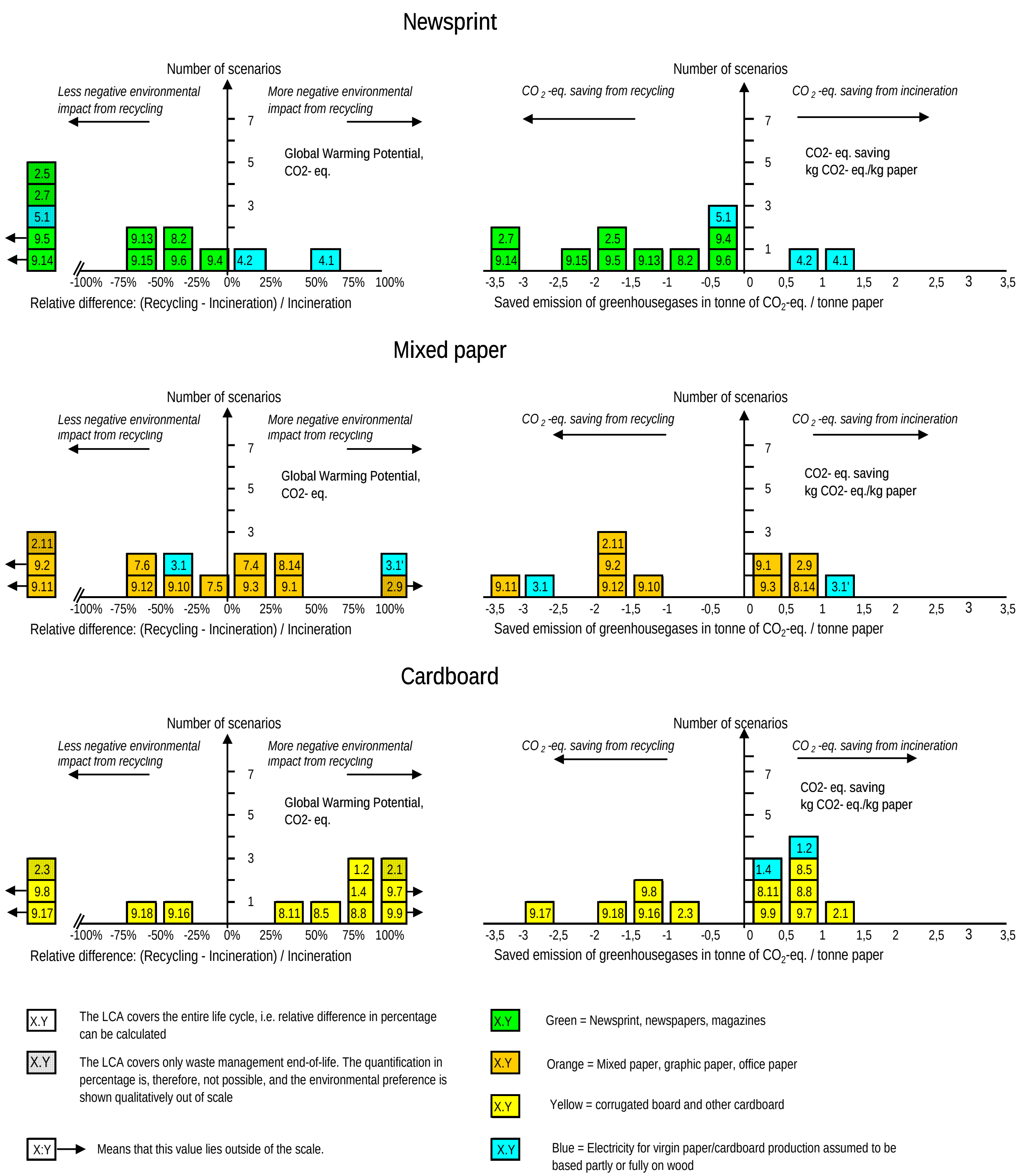


Figure 3.7. Recycling versus incineration ~ segregation of results on global warming impacts in frequency histograms for each the main paper/cardboard categories – showing the significance of assuming electricity for virgin paper/cardboard production being based partly or fully on wood

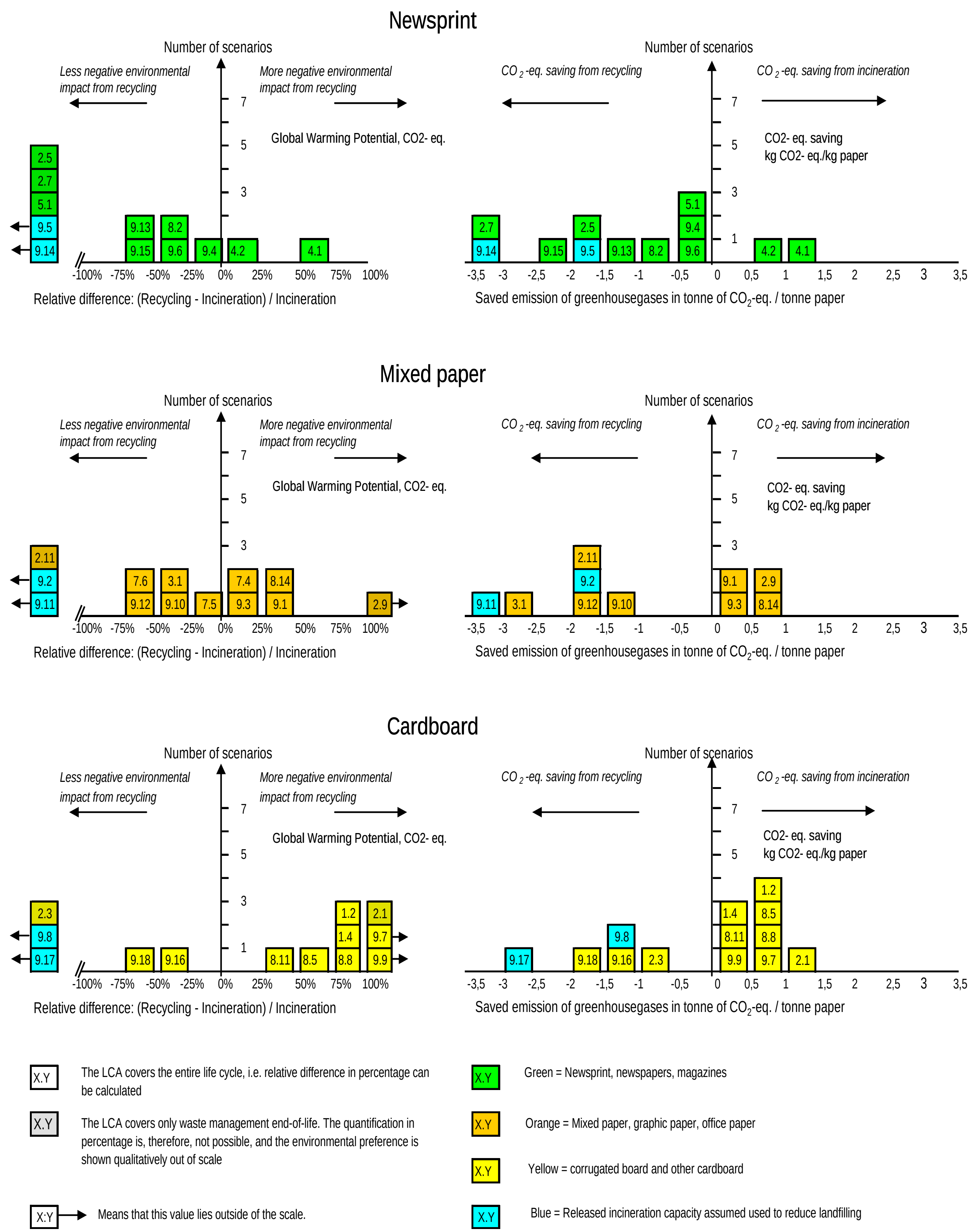


Figure 3.8. Recycling versus incineration ~ segregation of results on global warming impacts in frequency histograms for each the main paper/cardboard categories – showing the significance of assuming that incineration capacity released on recycling is used to take in burnable waste from landfills

3.3.4 The utilisation of released incineration capacity to reduce landfilling

Only one study, Frees *et al.,* (2004) considered the fact that recycling releases some incineration capacity in waste incineration plants, and that this capacity may then be used to take in more combustible waste from landfills. **Figure 3.8** shows that the assumption was highly significant and all scenarios that assumed the use of released incineration capacity to take in more waste from landfills found a very large CO_2 – eq. saving from recycling compared with incineration. The point is that using the released incineration capacity will result in both an avoided methane emission from landfills and an extra energy recovery from burnable waste in incinerators, giving rise to the avoided equivalent CO_2 – emissions from other energy sources.

3.3.5 The opportunity cost of using wood

Finally, there is the issue of the opportunity cost of using wood. Although the majority of scenarios did not consider any opportunity cost associated with the use of wood, in 3 out of the 9 studies, scenarios were found that did include it.

Virgin paper production uses more wood, resulting in the identified average of twice as much energy consumption overall. This wood consumption is saved when paper/ cardboard is recycled, and society has the opportunity of using this saved wood for energy purposes instead. Whether or not this should be included in an LCA is a matter of the future perspective of the study. Two reasons for including it can be argued.

First is that an overall socio-economic assessment comprising all societal costs, including environmental externalities (as addressed by a Cost/Benefit Analysis) would show a preference for recycling paper and using this saved wood for energy, instead of using it for virgin paper. Including the use of saved wood for energy in the LCA would then be simply to illustrate the environmental consequences of choosing this option.

The second reason is technically more stringent: if society increases its demand for wood as a means of reducing CO_2 emissions from the energy sector, wood may not be of unlimited availability in the future. This implies a direct opportunity cost due to the fact that any use of wood in virgin paper manufacture would then deprive society of the opportunity of using that wood for energy. This would incurr the cost of having to use other fuels, most likely fossil fuels containing non-biogenic carbon. In LCA terms, it means that fuels for energy purposes have one common pool/market, and wood and fossil fuels are components of that same market, in which wood is no longer a marginal fuel. Just like Norwegian hydropower should never be found as a marginal energy source in an LCA, because it is a priority source of electricity and not the marginal one, we can in this case not have wood in an LCA - and any use of wood shall in this case be included by an equivalent use of the marginal fuel on the market, which is probably then a fossil fuel. This line of thinking can be sustained by the developments in the energy sector. For instance, in Denmark over the last 5-10 years many power plant have taken wood chips and other biomass together with coal, and these plant can switch freely between these fuels. Moreover, the total available biomass in Denmark is not nearly enough to comply with the Kyoto CO_2 reduction targets, so availability of biomass is already a limiting factor in Denmark. A quick calculation of the same relation for Europe shows that all excess biomass derived from all European forests (all biomass production capacity that is not harvested today) could only reduce European CO_2 emissions by 2 % when substituting coal - and Europe's energy consumption increases by 1% a year. Excess agricultural biomass is not included in this calculation, but it indicates that there is not that much biomass available to help with European energy needs.

When representing a future of limited availability of biomass, the opportunity cost of using wood should be included in an LCA, and when such opportunity costs have been included, all scenarios showed a clear preference for recycling, as shown in **Figure 3.9**.
All scenarios assuming an opportunity cost for using wood found a substantial saving from paper/cardboard recycling compared with incineration. As is most evident for cardboard, it is really a matter of two distinctly different data populations, one representing scenarios that assumed an opportunity cost and one representing scenarios that didn't.

All main disparities in recycling versus incineration scenarios have now been explained. For example, for cardboard it has been found that having CO_2-eq. savings from recycling presupposes either that recycling can release incineration capacity that can be utilised to reduce landfilling of burnable waste or that there is an opportunity cost of using wood in the sense that it deprives society the opportunity of using it in the energy sector. Conversely, having CO_2-savings from incineration presupposes that there is no use for released incineration capacity and no opportunity cost from using wood in the manufacture of virgin materials.

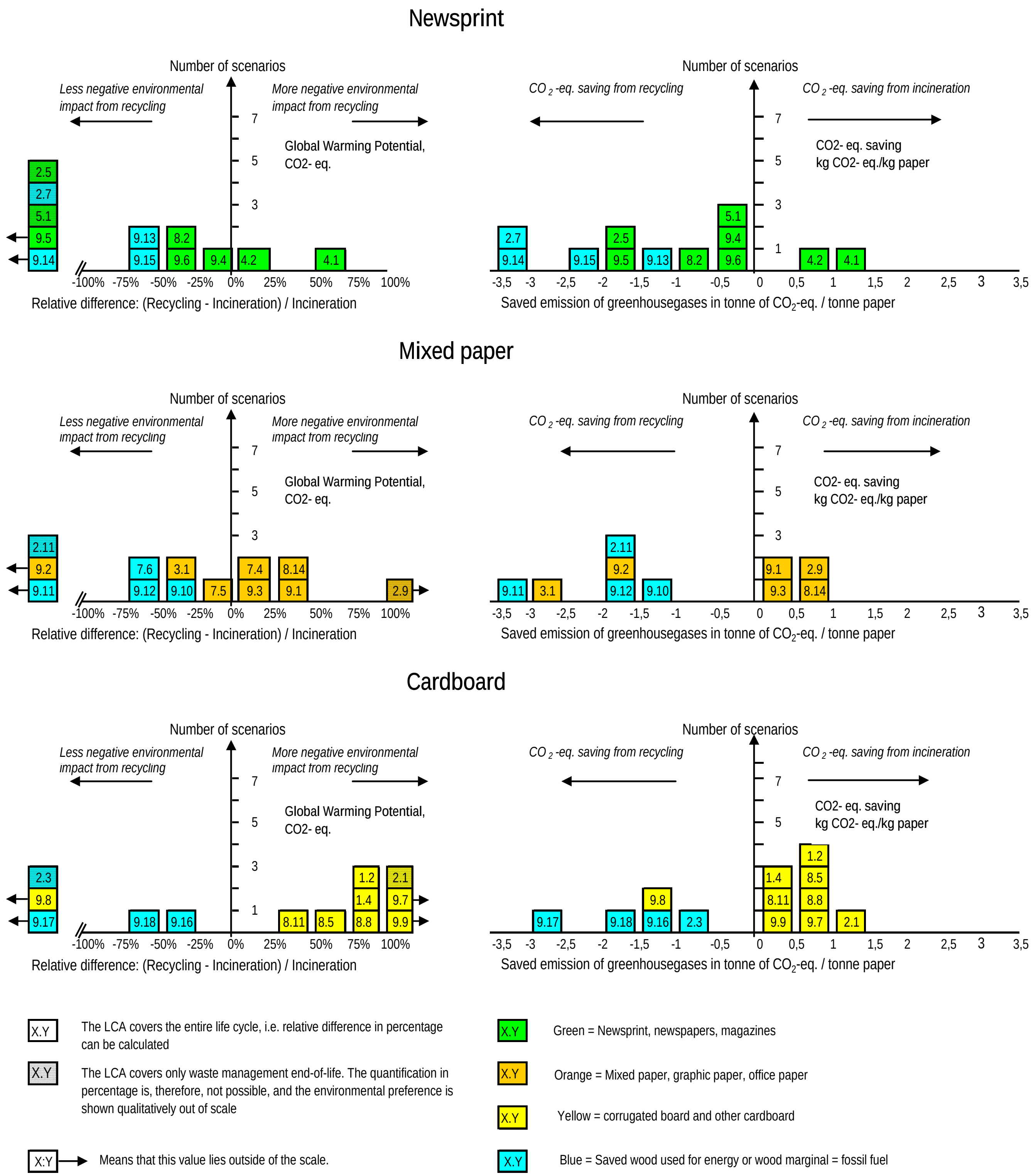


Figure 3.9. Segregation of results on global warming impacts in frequency histograms for each the main paper/cardboard categories – showing the significance of assuming an opportunity cost of using wood in terms of an equivalent use of fossil fuel in the energy sector

3.3 Glass

3.3.1 Main findings

The selection process identified 11 studies for detailed review, comprising 25 scenarios comparing waste management options(**Table 3.3)**. The overall finding was that closed loop glass recycling had a lower environmental impact than the alternatives of incineration or landfilling. There were, nevertheless, some studies deviating from the general picture, particularly where rather extreme scenarios have presupposed long transport distances.

Table 3.3 Summary of glass LCAs reviewed

Study no.	Waste material studied	Country/ region	Scenario no.	Waste handling comparison	Concluded environmental preference		
					Recycling	Incineration	Landfill
GL 1	Glass packaging	UK	1.1	Recycling vs. landfill	X	(n.a.)	
GL 2	Glass packaging	UK	2.1	Recycling vs. landfill	X	(n.a.)	
			2.2	Recycling vs. landfill	X	(n.a.)	
			2.3	Recycling vs. landfill	X	(n.a.)	
			2.4	Recycling vs. landfill		(n.a.)	X
			2.5	Recycling vs. landfill		(n.a.)	X
			2.6	Recycling vs. landfill	X	(n.a.)	
			2.7	Recycling vs. landfill	X	(n.a.)	
GL 3	Glass packaging	Australia	3.1	Recycling vs. landfill	X	(n.a.)	
GL 4	Glass in MSW	Spain	4.1	Recycling vs. landfill	X	(n.a.)	
GL 5	Glass beer bottles	Denmark	5.1	Recycling vs. incineration	X		(n.a.)
GL 6	Glass packaging	Europe	6.1	Recycling vs. incineration	X		(n.a.)
			6.2	Recycling vs. incineration	X		(n.a.)
			6.3	Recycling vs. incineration	X*	X*	(n.a.)
			6.4	Recycling vs. incineration	X		(n.a.)
GL 7	Glass packaging	Europe	7.1	Recycling vs. landfill	X	(n.a.)	
			7.2	Recycling vs. incineration	X		(n.a.)
GL 8	Glass in MSW	Europe	8.1	Recycling vs. incineration	X		(n.a.)
			8.2	Recycling vs. landfill	X	(n.a.)	
GL 9	Glass packaging	Sweden	9.1	Recycling vs. landfill	X	(n.a.)	
			9.2	Recycling vs. landfill	X	(n.a.)	
GL 10	Glass in MSW	USA	10.1	Recycling vs. landfill	X	(n.a.)	
			10.2	Recycling vs. incineration	X		(n.a.)
GL 11	Glass packaging	UK	11.1	Recycling vs. landfill	X	(n.a.)	
			11.2	Recycling vs. incineration	X		(n.a.)

N.a. = "Not applicable"   * No clear preference

Most of these studies had a focus on packaging waste, where container glass was one of the analysed materials. From the currently published LCA study types; these have been generally well suited to the scope of this review. However, such studies can present difficulties as data sources are often generic and not associated to specific glass manufacturing sites, and some of the studies therefore lacked some insight into the specifics of the glass industry.

The assumptions that were found to have the highest influence on LCA outcomes were those related to the interdependency of the glass waste handling system on the energy system of the surrounding technosphere, including:

- the type of energy used for manufacture of primary glass;
- the type of energy used for manufacture of secondary glass from recycled cullet;
- the type of recycling process applied (closed loop recycling appeared to be preferable to open loop recycling processes)

Table 3.4 provides an overview of the 16 identified essential system boundary criteria for glass, divided by life cycle stage. The table also gives an overview of the extent to which these issues were explicitly dealt with by the 11 studies.

Even though the existing LCAs on glass were on average of good quality, there were some aspects of transparency in the justification of the assumptions made which were poorly dealt with, especially with regard to the description of the interactions with the energy system, as mentioned above.

Table 3.4 Overview of the extent to which the 16 key system boundary issues were considered in the glass LCA studies analysed

Code	System boundary conditions		Number of studies	% of the studies that consider in any of the scenarios the given boundary condition
Virgin material production				
1	Material marginal	Considered	11	100%
		No Inf.	0	-
2	Electricity marginal: which?	Considered	10	91%
		No Inf.	1	-
3	Steam marginal: which?	Considered	6	55%
		No Inf.	5	-
4	Co-products dealt with?	Yes/N.a.	0	0%
		No	11	-
Secondary material production				
5	Material marginal	Considered	10	91%
		No Inf.	1	-
6	Electricity marginal: which?	Considered	9	82%
		No Inf.	2	-
7	Steam marginal: which?	Considered	6	55%
		No Inf.	5	-
8	Co-products dealt with?	Yes/N.a.	0	0%
		No	11	-
Material recovery				
9	Product dependent material recovery included?	Yes	8	73%
		No	3	-
10	Type of product dependent material recovery	Considered/N.a.	8	73%
		No Inf.	3	-
Material disposal				
11	Disposal comparison	Considered	11	100%
		No Inf.	-	-
12	Emissions from landfill included?	Considered	11	100%
		No Inf.	0	-
13	Energy from incineration substitutes heat?	Considered/N.a.	10	91%
		No Inf.	1	-
14	Energy from incineration substitutes electricity?	Considered/N.a.	11	100%
		No Inf.	0	-
15	Alternative use of incineration capacity included?	Considered/N.a.	3	27%
		No Inf.	8	-
16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other)	Considered	6	55%
		No Inf.	5	-

3.3.2 Glass: Recycling vs. Incineration

As shown in **Figure 3.10**, the review found that recycling was more favourable than incineration in almost all the scenarios and all the environmental impact categories considered, in spite of the variations in study assumptions. However, one scenario (6.3) deviated from this general trend as it presupposed a poor recycling rate, collected glass from low-density areas and transporting it over long distances (500 km). Nevertheless, this situation was not considered 'typical' or 'representative' and the authors of Glass study-6 concluded that from an environmental point of view and considering mainly global impacts, glass waste should be recycled as much as possible. This conclusion was reached even though all scenarios in study GL-6 were slightly in favour of incineration as regards toxicity.

Recycling was the most favourable option compared with incineration in 6 scenarios from 3 different studies comprising the whole life cycle. The conclusions from these studies were supported by 2 scenarios from 2 LCA-like studies only focussing on the end-of-life phase (represented by the hatched boxes in the left side of the diagrams in **Figure 3.10**).

3.3.3 Glass: Recycling vs. Landfill

Figure 3.11 illustrates that recycling was clearly more favourable than landfill in all the scenarios and all the environmental impact categories considered.

This conclusion was based on 13 scenarios from 6 different studies comprising the whole life cycle. The conclusions from these studies were supported by 3 scenarios from 3 LCA-like studies only focussing on the end-of-life phase (represented by the hatched boxes in the left side of the diagrams in **Figure 3.11**).

Though the majority of analysed scenarios were clearly in favour of recycling, two scenarios attributed a slight advantage to landfill. These scenarios were both related to non-closed loop recycling, where glass was utilised in water filtration media and aggregates respectively. In both cases the energy required for recycling glass exceeded the energy consumed through the production of traditional virgin materials such as aggregates and conventional water filtration media. Thus, the global warming potential was slightly higher for the recycling option, although further research would be required in the case of water filtration media that includes a full evaluation of the energy implications of the use phase compared with conventional filtration media.

3.3.4 Glass: Incineration vs. Landfill

None of the identified studies compared incineration and landfill.

Recycling vs. Incineration

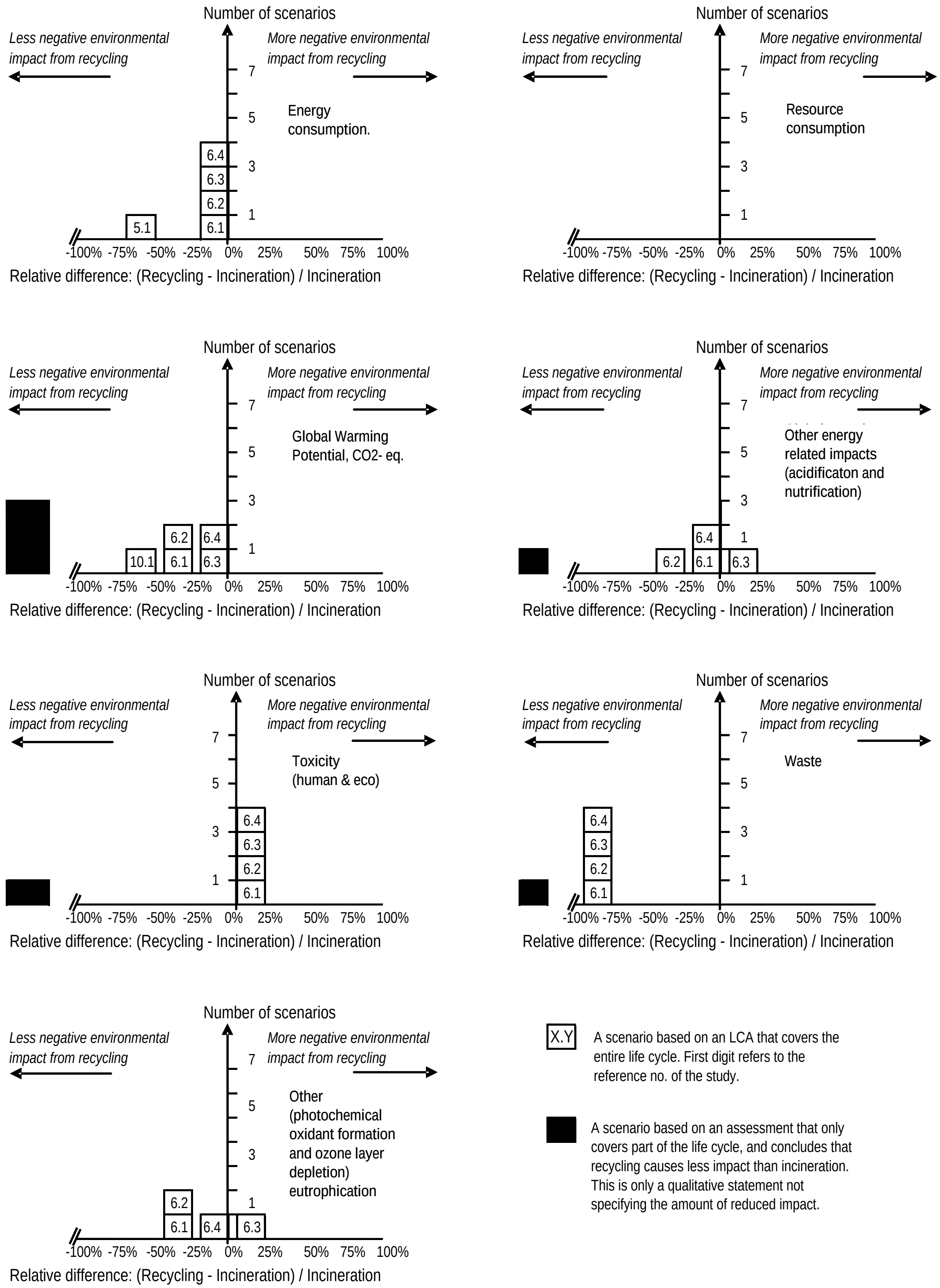


Figure 3.10 Frequency functions of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. incineration. A negative value means that recycling causes less impact than incineration

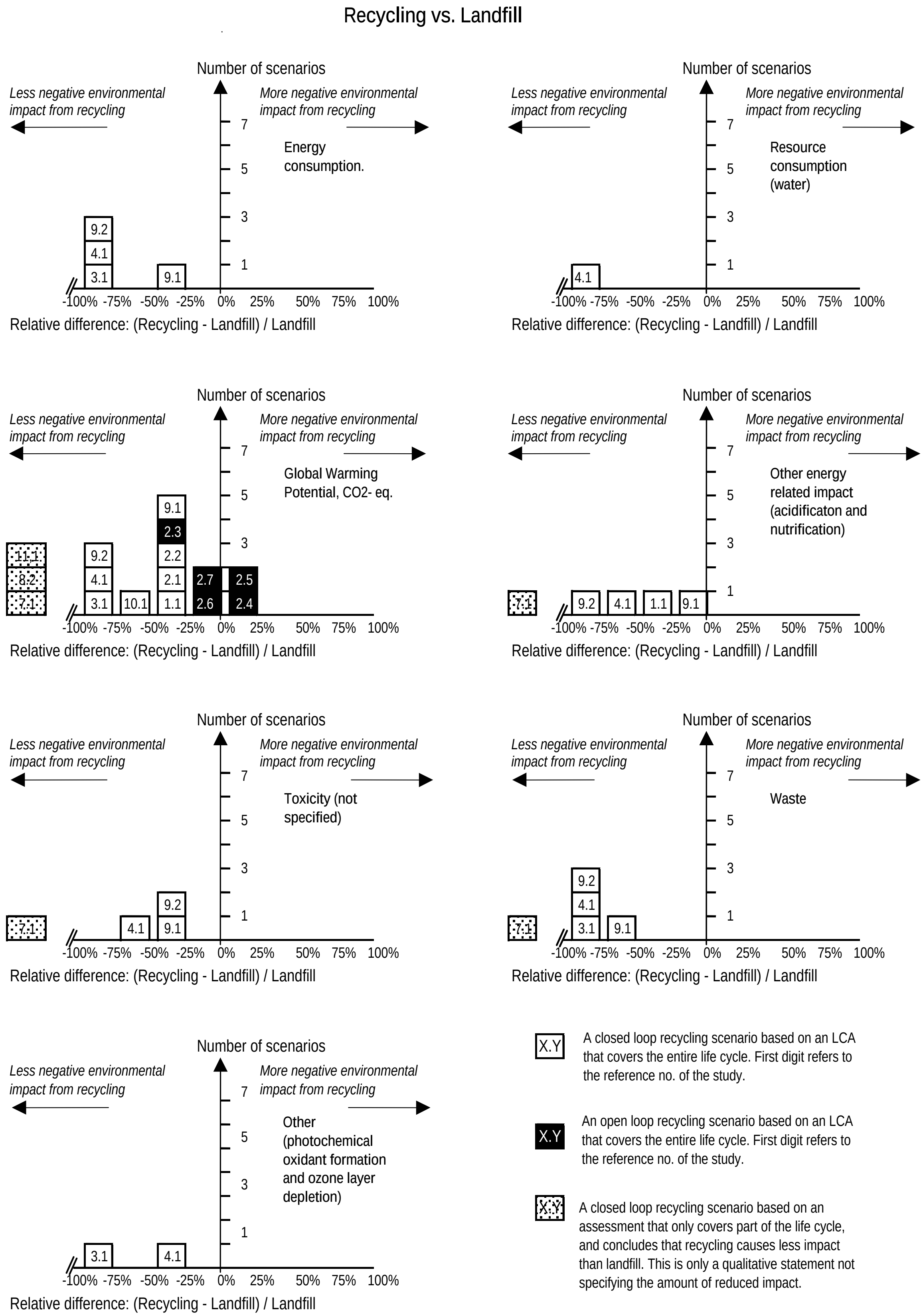


Figure 3.11 Frequency functions of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. incineration. A negative value means that recycling causes less impact than landfill

3.3.5 Glass: Greenhouse gas savings

Figure 3.12 presents the results from the LCA studies reviewed on greenhouse gas savings achieved by recycling, as compared to landfilling or incineration.

With the exception of the scenario 2-4 and 2-5, all studies indicated that there were greenhouse gas emissions saving through glass recycling. The majority of scenarios (both incineration and landfill comparisons) indicated savings in the range up to 0.50 kg CO_2-equivalents/kg glass. On average the savings achieved through recycling is 0.60 kg CO_2-equivalents/kg glass compared with incineration and 0.43 kg CO_2-equivalents/kg glass compared with landfilling.

However, the above figures covered both open and closed loop recycling. Closed loop recycling scenarios indicated a greenhouse gas emission saving that ranged from 0.58 to 0.60 kg CO_2-equivalents/kg glass compared with landfilling/incineration.

The benefit of open loop recycling was more ambiguous as the saving in CO_2-equivalents was highly dependent on the type of open loop recycling applied. Whilst recycling glass into glass fibre insulation, clay bricks and to a lesser extent also shot blast abrasive, entail savings in CO_2-equivalent emissions (0.28, 0.07 and 0.02 kg CO_2-equivalents/kg glass respectively), recycling into aggregate or water filtration media seemed to imply an increase in CO_2-equivalent emissions (0.002 and 0.04 kg CO_2-equivalents/kg glass respectively). It should be noted that all of the scenarios that considered open loop recycling originated from a single study (GL-2) performed on behalf of the British Glass Manufacturers Confederation. No additional studies considering open loop recycling were identified during the literature search. Hence, the conclusions drawn from the present review regarding open loop recycling should be treated with some caution. Further work will be required to examine all aspects of product use in open loop systems. For instance, if the use of cullet in water filtration media confers greater pumping efficiencies in water systems, this aspect needs to be reflected in the LCA.

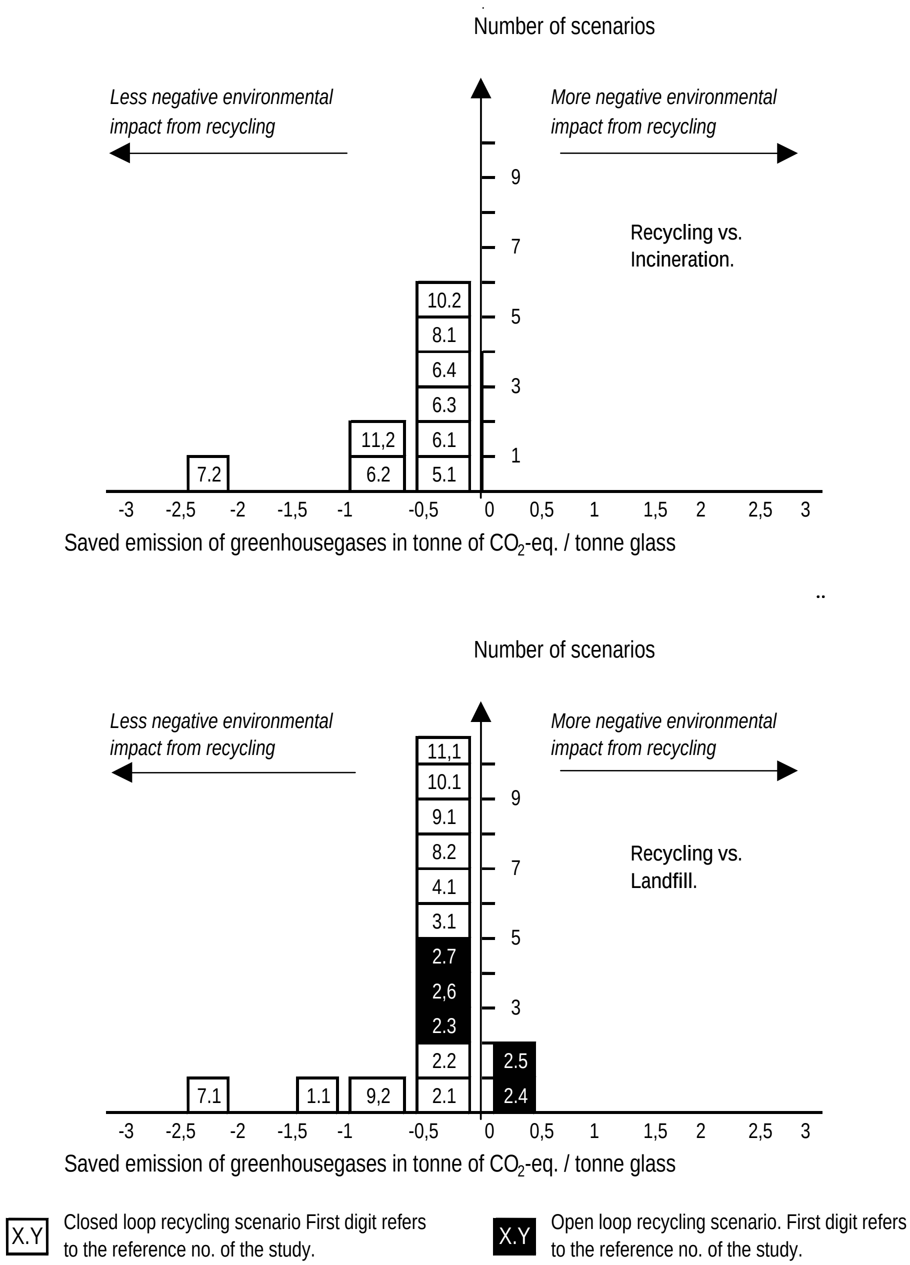


Figure 3.12 Frequency functions of the distribution of results from the various scenarios of the reviewed studies showing the saved emission of greenhouse gases from recycling vs. incineration and recycling vs. landfill respectively. A negative value (the left side of the diagrams) means that recycling causes a saving compared to incineration or landfill.

To summarise, this review showed that the type of glass recycling applied can be an important issue when determining the relative advantage of recycling compared with either landfilling or incineration. Hence, closed loop glass recycling appeared to be superior to both incineration and landfilling in environmental terms, whereas some types of open loop recycling appeared to be more marginal or even disadvantageous.

Consequently, generation of information on the life cycle wide environmental implications of alternative open loop glass recycling options would be relevant as a subject for further and fuller investigation.

3.4 Plastics

3.4.1 Main Findings

In total the review covered 60 scenarios of high quality LCAs covering a variety of countries and the conclusions were in general believed to be robust. An overview of the reviewed studies and scenarios is presented in **Table 3.5**. The table also indicates the overall conclusion on environmental preference between the compared waste management options.

Based on experience and on the results of the reviewed studies, a number of system boundary issues have been identified that are decisive to the results and conclusions of the study. All of the reviewed studies have been assessed with respect to their handling of each of the 16 key boundary issues in **Table 3.6**.

As is evident from **Table 3.6**, around half of the studies were transparent about what type of material, be it virgin or secondary, and what type of energy marginal was anticipated by the study. This did not mean that the other studies had done something incompatible with LCA methodology, but that these studies were not explicit about their treatment of a particular issue.

In many cases, data from LCA databases on materials had been adopted within the studies without stating further details. On the issue of co-products from virgin materials, only 20% of the reviewed studies stated how co-products were dealt with. Knowing that oil cracking/refining has co-production of several monomers, this was an apparent methodological gap. It is, however, known amongst LCA practitioners that data on the various polymers as they are provided by the Association of Plastic Manufacturers in Europe, APME, are provided in an allocated form in all available databases, i.e. data are given per monomer (and subsequent polymer) by some means of allocation. As these data in practice are the only data available for virgin plastics, any data set most probably derives from APME data anyhow. Consequentially, it means that co-products were in fact dealt with in practice, and the lack of information was only a transparency issue.

The pre-processing of the collected material before recovery, typically cleaning/washing, is an essential part of most plastics systems, and in all cases where this was relevant, it was considered and included.
The overall conclusion was that the reviewed studies represented a resonable handling of the system boundary issues for plastics. The review concluded that the applied system boundaries and assumptions divided the studies and their scenarios into three main categories that differed so much from each other that they should be addressed as separate groups of scenarios, namely:

I. Scenarios that anticipated recovered material to substitute virgin material of the same kind in the weight/weight ratio of 1:1
II. Scenarios that anticipated recovered material to substitute virgin material of the same kind in the weight/weight ratio of 1:0.5
III. Scenarios that included substantial washing/cleaning of the plastic product before material recovery was possible, in which this washing/cleaning had the dominating environmental significance

The vast majority of scenarios belonged to group I. With this basic assumption for material recovery, all reviewed studies and scenarios concluded that recycling/material recovery was environmentally better than both incineration and landfilling on all environmental impact categories included in the studies, with recycling being around 50 % better on average. The net CO_2 saving from recycling was found to be 1.5 – 2 tonnes CO_2-eq. per tonne of plastics on average.

In cases where the quality/grade of the recovered plastic implied a less favourable substitution ratio (worse that 1:1), the scenarios dealing with this issue demonstrated that a ratio of 1:0.5 was about the break-point at which recycling and incineration with energy recovery were environmentally equal.

In scenarios where washing/cleaning was needed, the scenarios dealing with this demonstrated that this may lead to incineration being environmentally preferable to recycling. The reason was the need for hot water for washing and the fact that the organic contaminants have a heat value that is an advantage in the incineration scenarios, but a disadvantage in recycling, because the removal of contaminants in municipal wastewater treatment required energy.

Table 3.5 Summary of plastics LCAs reviewed

St. no.	Country/ region	Waste material studied	Product	Scen. no.	Waste handling comparison	Material recovery concept	Material substitution on recycling	Concluded environmental preference		
								Recycl.	Incin.	Landf.
01	Europe (mainly Germany and Denmark)	PVC	Cables	1.1	Recycling vs. incineration	Mechanical	Virgin PVC	X		n.a.
				1.2	Recycling vs. landfill	Mechanical	Virgin PVC	X	n.a.	
				1.3	Recycling vs. incineration	Chemical	PE and NaCl	X		n.a.
				1.4	Recycling vs. landfill	Chemical	PE and NaCl	X	n.a.	
				1.5	Incineration vs. landfill	n.a.	n.a.	n.a.	(X)	(X)
02	Western Europe	PP	Car bumpers	2.1	Recycling vs. incineration	Mechanical	Virgin PP	X		n.a.
				2.2	Recycling vs. incineration in cement kiln	Mechanical	Virgin PP	X		n.a.
				2.3	Recycling vs. landfill	Mechanical	Virgin PP	X	n.a.	
				2.4	Incineration vs. landfill	n.a.	n.a.	n.a.	X	
				2.5	Incineration in cement kiln vs. landfill	n.a.	n.a.	n.a.	X	
03	Norway	Mainly PE	MSW	3.1	Recycling vs. landfill	Mechanical	Virgin PE	X	n.a.	
				3.2	Recycling vs. landfill	Mechanical	Virgin PE	X	n.a.	
04	Norway	PET	Bottles	4.1	Recycling vs. landfill	Mechanical	Virgin PET	X	n.a.	
				4.2	Recycling vs. incineration	Mechanical	Virgin PET	X		n.a.
05	New Zealand – Hawke's Bay	HDPE	Farm containers	5.1	Recycling vs. landfill	Mechanical	Virgin HDPE	X	n.a.	
				5.2	Recycling vs. incineration	Mechanical	Virgin HDPE	X		n.a.
		LDPE	Field cover & hay wrap	5.3	Recycling vs. landfill	Mechanical	Virgin LDPE	X	n.a.	
				5.4	Recycling vs. incineration	Mechanical	Virgin LDPE	X		n.a.
	New Zealand – Canter-bury	HDPE	Farm containers	5.5	Recycling vs. landfill	Mechanical	Virgin HDPE	X	n.a.	
				5.6	Recycling vs. incineration	Mechanical	Virgin HDPE	X		n.a.
		LDPE	Field cover & hay wrap	5.7	Recycling vs. landfill	Mechanical	Virgin LDPE	X	n.a.	
				5.8	Recycling vs. incineration	Mechanical	Virgin LDPE	X		n.a.
06	Sweden	HDPE/ LDPE	Household waste	6.1	Recycling vs. incineration	Mechanical	PE : wood 80 : 20	X		n.a.
				6.2	Recycling vs. incineration	Mechanical		X		n.a.
07	EU	HDPE	MSW	7.1	Recycling vs. incineration (without energy recovery)	Mechanical	Virgin HDPE	X		n.a.
				7.2	Recycling vs. incineration (with energy recovery)	Mechanical	Virgin HDPE	X		n.a.
		PET		7.3	Recycling vs. incineration (without energy recovery)	Mechanical	Virgin PET	X		n.a.
				7.4	Recycling vs. incineration (with energy recovery)	Mechanical	Virgin PET	X		n.a.
		HDPE		7.5	Recycling vs. landfill	Mechanical	Virgin HDPE	X	n.a.	
		PET		7.6	Recycling vs. landfill	Mechanical	Virgin PET	X	n.a.	
08	USA	HDPE	MSW	8.1	Recycling vs. landfill	Mechanical	Virgin HDPE	X	n.a.	
				8.2	Recycling vs. incineration	Mechanical	Virgin HDPE	X		n.a.
		LDPE		8.3	Recycling vs. landfill	Mechanical	Virgin LDPE	X	n.a.	
				8.4	Recycling vs. incineration	Mechanical	Virgin LDPE	X		n.a.
		PET		8.5	Recycling vs. landfill	Mechanical	Virgin PET	X	n.a.	
				8.6	Recycling vs. incineration	Mechanical	Virgin PET	X		n.a.
09	Denmark	LDPE	Household packaging waste (packaging for ketchup, mayonnaise shampoo, etc.)	9.1	Recycling vs. incineration	Mechanical	Virgin LDPE	X		n.a.
		PP		9.2	Recycling vs. incineration	Mechanical	Virgin PP		X	n.a.
				9.3	Recycling vs. incineration	Mechanical	Virgin PP		X	n.a.
				9.4	Recycling vs. incineration	Mechanical	Virgin PP		X	n.a.
				9.5	Recycling vs. incineration	Mechanical	Virgin PP	X		n.a.
				9.6	Recycling vs. incineration	Mechanical	Virgin PP	(X)	(X)	n.a.
				9.7	Recycling vs. incineration	Mechanical	Virgin PP		X	n.a.
				9.8	Recycling vs. incineration	Mechanical	Virgin PP		X	n.a.
10	EU	PET	Household packaging waste	10.1	Recycling vs. incineration	Mechanical	Virgin PET	X		n.a.
				10.2	Recycling vs. incineration	Mechanical	Virgin PET	X		n.a.
				10.3	Recycling vs. incineration	Mechanical	Virgin PET	(X)	(X)	n.a.
				10.4	Recycling vs. incineration	Mechanical	Virgin PET	X		n.a.
		PVC		10.5	Recycling vs. incineration	Mechanical	Virgin PVC	X		n.a.
				10.6	Recycling vs. incineration	Mechanical	Virgin PVC	X		n.a.
				10.7	Recycling vs. incineration	Mechanical	Virgin PVC		X	n.a.
				10.8	Recycling vs. incineration	Mechanical	Virgin PVC	X		n.a.
		LDPE		10.9	Recycling vs. incineration	Mechanical	Virgin LDPE	X		n.a.
				10.10	Recycling vs. incineration	Mechanical	Virgin LDPE	X		n.a.
				10.11	Recycling vs. incineration	Mechanical	Virgin LDPE		X	n.a.
				10.12	Recycling vs. incineration	Mechanical	Virgin LDPE	X		n.a.
		HDPE		10.13	Recycling vs. incineration	Mechanical	Virgin HDPE	X		n.a.
				10.14	Recycling vs. incineration	Mechanical	Virgin HDPE	X		n.a.
				10.15	Recycling vs. incineration	Mechanical	Virgin HDPE		X	n.a.
				10.16	Recycling vs. incineration	Mechanical	Virgin HDPE	X		n.a.

Table 3.6 Overview of the extent to which the 16 key system boundary issues were considered in the plastics LCA studies analysed

Issue no.	System boundary conditions		Number of studies	% of the studies that consider the assumption
Virgin material production				
1	Material marginal: which?	Considered	5	50%
		No Inf.	5	-
2	Electricity marginal: which?	Considered	5	50%
		No Inf.	5	-
3	Steam marginal: which?	Considered	5	50%
		No Inf.	5	-
4	Co-products dealt with?	Yes/N.a.	2	20%
		No	8	-
Secondary material production				
5	Material marginal: which?	Considered	4	40%
		No Inf.	6	-
6	Electricity marginal: which?	Considered	4	40%
		No Inf.	6	-
7	Steam marginal: which?	Considered	0	0%
		No Inf.	10	-
8	Co-products dealt with?	Yes/N.a.	10	100%
		No	0	-
Material recovery				
9	Product dependent material recovery included?	Yes	6	60%
		No	4	-
10	Type of product dependent material recovery	Considered/N.a.	10	100%
		No Inf.	-	-
Material disposal				
11	Disposal comparison	Considered	10	100%
		No Inf.	0	-
12	Emissions from landfill included?	Considered	6	60%
		No Inf.	4	-
13	Energy from incineration substitutes heat?	Considered/N.a.	10	100%
		No Inf.	0	-
14	Energy from incineration substitutes electricity?	Considered/N.a.	10	100%
		No Inf.	0	-
15	Alternative use of incineration capacity included?	Considered/N.a.	0	0%
		No Inf.	10	-
16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other)	Considered	8	80%
		No Inf.	2	-

n.a. = not applicable; No Inf. = no information

3.4.2 Plastics: Recycling vs. Incineration

Figure 3.13 illustrates that recycling was more favourable than incineration in the vast majority of the scenarios and all the environmental impact categories considered, with an average environmental improvement from recycling of 25 – 50%. An outlying part of the data range was due to specific identifiable assumptions within the scenarios giving rise to superiority of incineration. In two of the ten reviewed studies, scenarios were found in which incineration was environmentally superior to recycling. These studies contained scenarios with system boundary assumptions that were different from the rest, implying that these scenarios constituted their own separate populations. For this reason, they have been separately colur-coded in the graphs. The distribution illustrated in **Figure 3.13**, therefore, is not the frequency function of data from one data population, but rather a combined function of data from at least three populations, namely:

- The main population characterised by the common denominator that recovered material substituted virgin material in the weight/weight ratio of 1:1, shown in white boxes in the figures.
- A special population characterised by the common denominator that recovered material substituted virgin material in the weight/weight ratio of 1:0.5, shown in yellow boxes in the figures.
- A special population characterised by the common feature that the plastic product contained so much COD (organic material) that operations of washing/cleaning, COD removal in municipal waste water treatment plants and COD incineration in waste incinerators all together favour incineration over recycling. These scenarios are shown in orange boxes in the figures.

These three distinct populations are identified in the graphs that summarise the different impact categories in **Figure 3.13** . For overall energy consumption this analysis is elaborated further in **Figure 3.14** for these three fundamental system boundary assumptions.

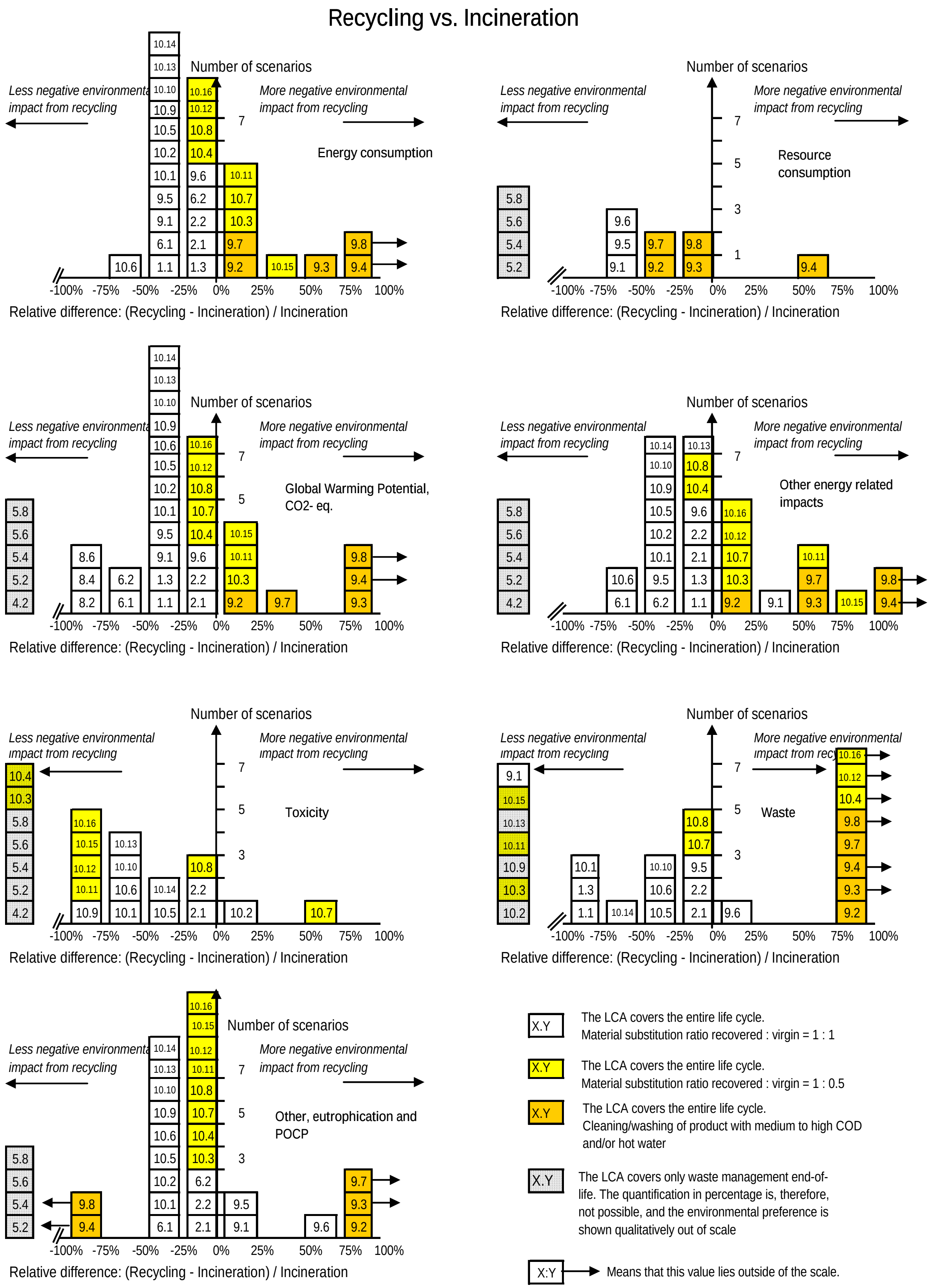


Figure 3.13 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. incineration. A negative value means that recycling causes less impact than incineration

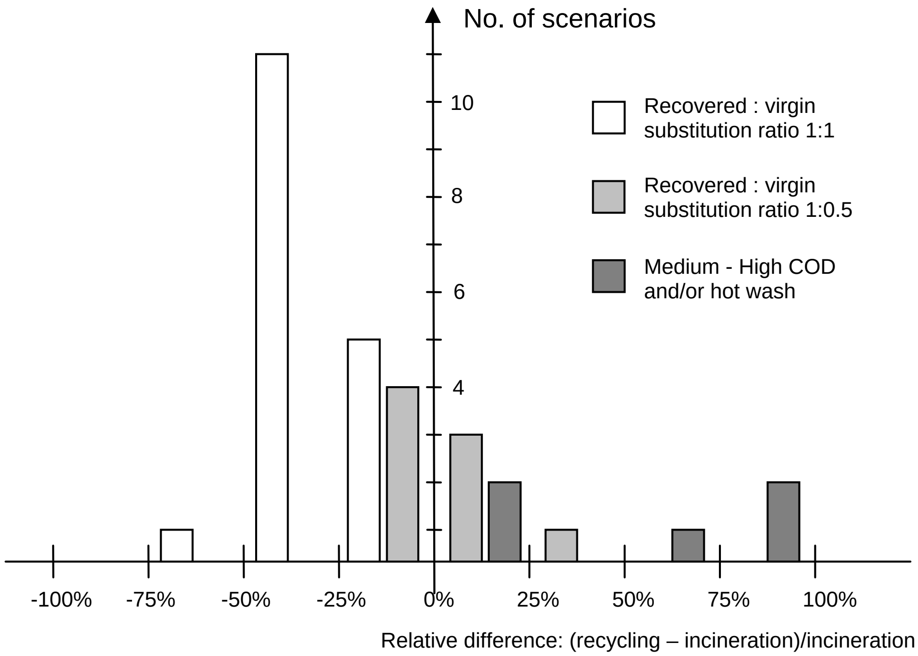


Figure 3.14. *Frequency functions of the distribution of results on overall energy consumption from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. incineration – segregated into the three underlying data populations divided on key system boundary assumptions*

It is evident from **Figure 3.14** that the main data population shows a clear environmental preference for recycling over incineration, with an average reduction of total life cycle energy consumption of 25 – 50 %. This main population of scenarios anticipated that recovered plastic can substitute virgin plastic of the same kind with a weight/weight substitution ratio of 1:1. The scenarios within this population contained a variety of plastic polymers, namely PVC, PP, PE (both LDPE and HDPE) and PET. Given the assumed substitution ratio, the polymer type did not seem to be decisive in the relative difference between recycling and incineration. The key explanation was that the heat value (to be recovered on incineration) was only half or less than the total primary energy content of the polymer including process energy from oil/gas to polymer (to be saved on mechanical material recovery).

It was, however, also evident that the assumption that recovered plastic can substitute virgin of the same kind in a weight/weight substitution ratio of 1:1 was a key assumption to make. As **Figure 3.14** shows, a substitution ratio of 1:0.5 will lead to incineration being slightly more favourable on energy consumption, but only slightly. The explanation for the difference being no greater was the same as mentioned above, namely that the energy gain from mechanical material recovery was twice as high as from energy recovery, and including the energy needed for the material recovery process itself, a picture like the one shown would be intuitively expected. It can be concluded that a substitution ratio just a little better than 1:0.5 would represent the break-even between mechanical material recovery and energy recovery for the plastic types comprised by this study (PET, PVC, LDPE and HDPE).

It is, finally, also evident that a requirement for cleaning/washing of plastic products before material recovery can eliminate the benefit of material recovery. Especially when, like in this case, there is a high content of organic matter that would have been an energy benefit in an incinerator with utilisation of the recovered energy, but is only a source of energy consumption in the municipal waste water treatment plant subsequent to the cleaning.

As the two ‘outlier’ populations were essential to the conclusions made, more details on these are given below.

The material substitution ratio

Study no. 10 (Coopers & Lybrand, 1997) included, as mentioned, the scenarios of the substitution ratios of 1:0.5. In general, this study operated with what can be termed ’optimistic’ and ’pessimistic’ scenarios for recycling and incineration respectively. Only scenarios with the combination of pessimistic conditions for recycling and optimistic conditions for incineration favoured incineration. **Table 3.7** below indicates some of the attributes behind the definition on ’optimistic’ and ’pessimistic’ conditions in this study.

Table 3.7. Some of the system boundary conditions defining the ‘optimistic’ and ‘pessimistic’ scenarios respectively in glass study 10 (Coopers & Lybrand, 1997)

		Optimistic	**Pessimistic**
Recycling	Number of collections/year	104 (high density)	20 (low density)
	Sorting losses households	3%	10%
	% of (perfectly) distributed inhabitation	0% (high density)	33% (low density)
	Material substitution ratio	1:1	1:0.5
	Distances to recycling	23-39 km	346-980 km
	Distance/kg transported by consumer to container park	0.1 km/kg	1 km/kg
Incineration	Incineration rate	1	1
	Energy recovery application rate	1	1
	Energy recovery efficiency	0.25	0.15

The authors of the study concluded that the material substitution ratio is an important parameter. A ratio close to 1:1 is favourable to recycling. The authors, moreover, stated that even if the ratio of 1:1 is achievable for the mechanical properties some other characteristics such as product lifetime, surface polish and resistance to chemicals can make recycled products less advantageous environmentally (the study recommends further studies in this area).

Product dependant washing/cleaning

Study no. 9 (Frees, 2001), especially scenario 9.2 to 9.8, addressed plastic packaging in household waste – and specifically containers with significant residues from shampoo, honey, ketchup, mayonnaise etc. Residues of these contents are contaminants and must be washed out before recycling – either by the consumer or by the recycling plant. Because the contaminants are primarily organic, they can give rise to a significant COD load on the municipal waste water treatment plant, and therefore the contaminants were measured by their COD content. On the other hand, the organic contaminants release heat when combusted in an incineration plant. In the study, the COD content was classified into 'none', 'low', 'medium' and 'high'. The scenarios are shown in the **Table 3.8**.

Table 3.8. The scenarios for COD content and cleaning of the types of household packaging waste within plastics study no. 9 (Frees, 2001)

Scenario	COD	Cleaning	Load from contamination [kg COD/kg plastic]
9.2	Low	Hot	0.03-0.3
9.3	Medium	Hot	0.3-1
9.4	High	Hot	> 1
9.5	None (clean)	Cold	< 0.03
9.6	Low	Cold	0.03-0.3
9.7	Medium	Cold	0.3-1
9.8	High	Cold	> 1

In summary, the reasons for the higher environmental burden of recycling compared with incineration for scenarios 9.2 to 9.8 were due to:

1. washing in hot water as opposed to cold washing (scenario 9.2, 9.3 and 9.4)
2. COD load causing energy consumption at the municipal waste water treatment plant (except for scenario 9.5 with no COD)
3. utilization of the heating value of COD in an incineration plant (except for scenario 9.5 with no COD).

All of these factors, specifically related to the COD content, favoured incineration. The heat value of the COD content and the electricity needed to treat COD in wastewater were the dominant factors – more dominating than the energy used for wash in hot water. So the more COD, the greater the benefit associated with incineration compared with recycling. An exception was the impact type "other", where the impact of eutrophication is represented. This was due to the facts that there was relatively high NOx emissions from the incineration in question and from the production of new plastic, whereas nitrogen and phosphorus nutrients are removed at the wastewater treatment plant subsequent to the washing. Consequentially, eutrophication was highest from the incineration scenarios.

Scenario 9.1 of study no. 9 concerned the use of LDPE foil in secondary packaging for e.g. transport, and the results of this scenario were more in line with the results of the other studies, and also fairly in line with scenario 9.5 with no COD and wash in cold water.

3.4.3 Plastics: Recycling vs. Landfill

In 8 of the 10 studies scenarios comparing recycling with landfilling were included. In total, however, only 25 % of all scenarios (15 out of 60 scenarios in total) included this comparison, and it is clear that the comparison between recycling and incineration has drawn the most attention in the reviewed studies.

The two outlier populations that had special system boundary assumptions for recycling did not include the recycling/landfilling comparison, and the picture in **Figure 3.15**, shows an unambiguous environmental benefit associated with recycling compared with landfilling across all impact categories.

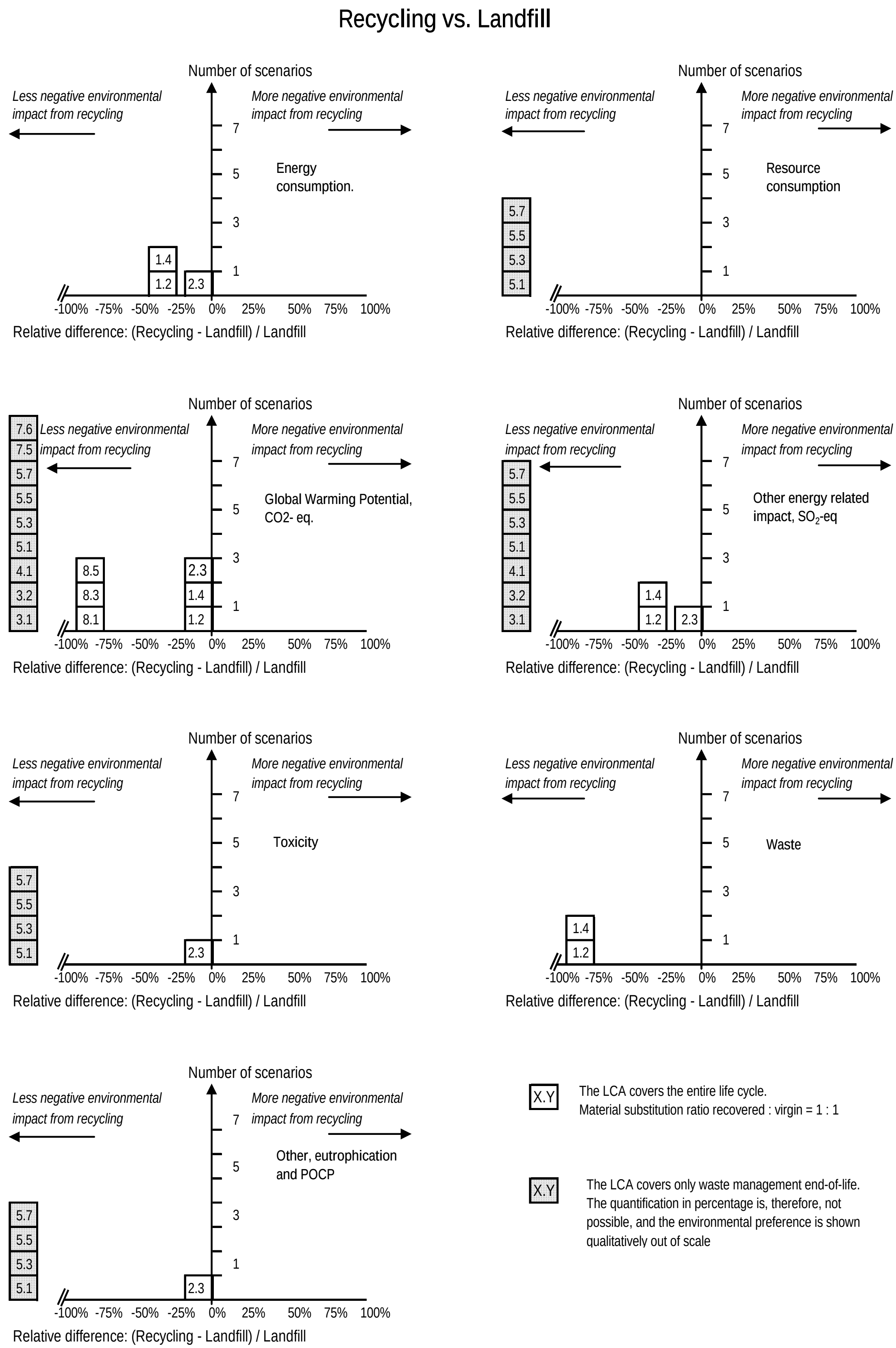


Figure 3.15 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. incineration. A negative value means that recycling causes less impact than landfill

3.4.4 Plastics: Incineration vs. Landfill

Studies 1 and 2, and only these, included scenarios comparing incineration with landfilling of plastics. The general conclusion from these two studies (three scenarios in total) was that incineration was environmentally preferable to landfilling: as shown in **Figure 3.16**. There was one outlier scenario, namely scenario 1.5 comparing incineration to landfilling of PVC implying an equal preference for the two.

Incineration vs. Landfill

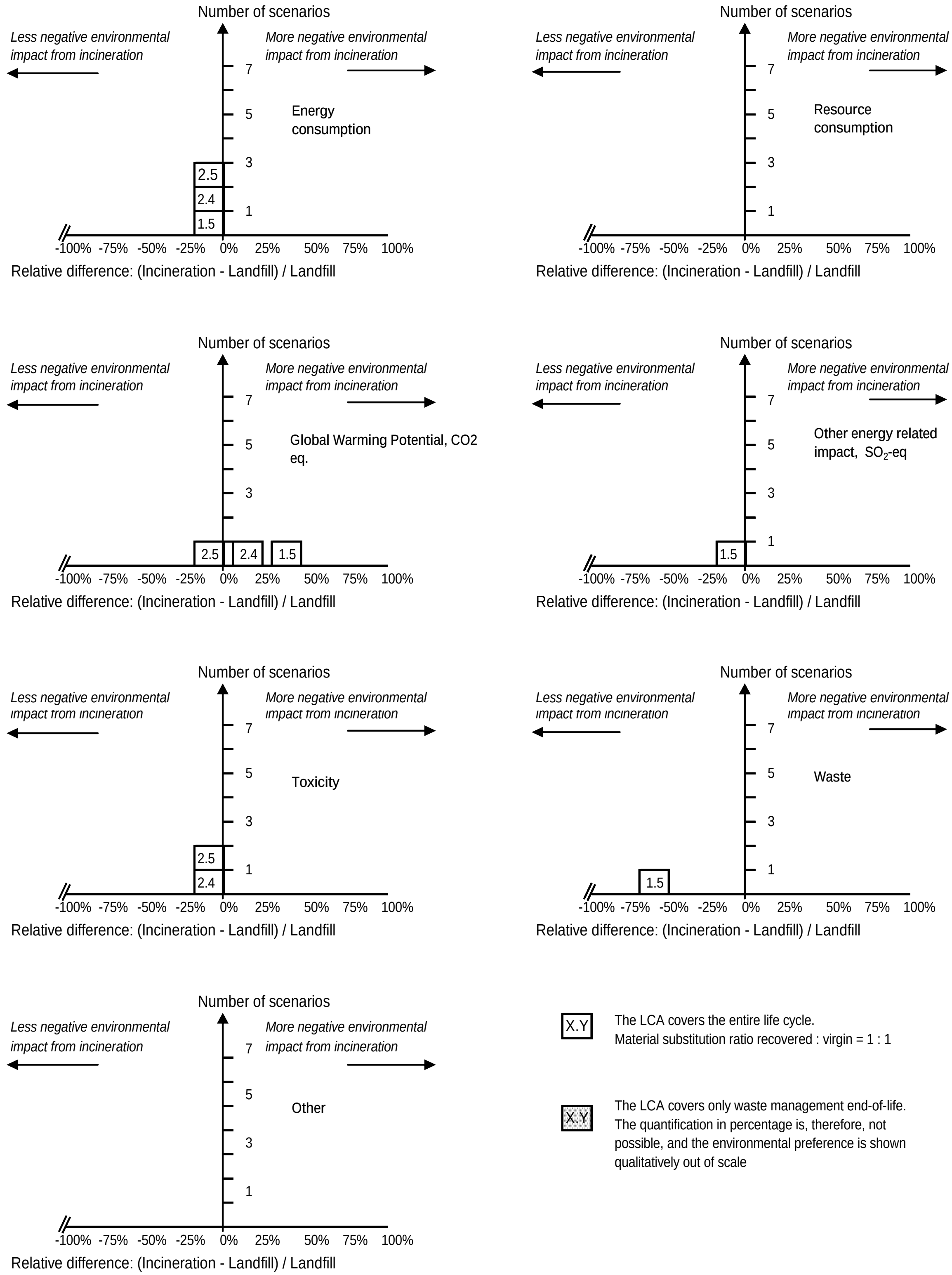


Figure 3.16 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. incineration. A negative value means that recycling causes less impact than incineration .

3.4.5 Plastics: Greenhouse gas savings

Figure 3.17 shows the net difference between overall emissions of greenhouse gases (GHGs) expressed as CO_2-equivalents. In practice, only CO_2 contributes significantly from the systems studied, as there essentially are no other GHGs involved. The Figure shows an unambiguous advantage to plastics recycling within the main population of scenarios that anticipated a virgin material substitution ratio of 1:1. The net CO_2 saving from recycling instead of the incineration of plastics, in this case, ranged from 0 to 4 tons of CO_2-eq. per tonne of plastics with an average around 2 tonnes CO_2-eq. per tonne of plastic.

As also shown in **Figure 3.17**, the net saving of CO_2-emission reported in the comparison of the various scenarios that included landfilling was found in the range of 0-2.5 tonnes CO_2-eq. per tonne of plastic, with an average of around 1.5 tonnes CO_2-eq. per tonne of plastic.

As already discussed in section 3.4.2, based on scenarios 3 and 4 of study 10 (Coopers & Lybrand), it appears that a recovered material to virgin material substitution ratio of around 1:0.5 was the break-even making recycling and incineration equal on CO_2-emission. However, this conclusion must be treated with caution as it is derived from a relatively limited dataset.

From study 9 (Frees, 2001) it can be acknowledged that washing/cleaning of products can reverse any CO_2-saving from recycling to a CO_2 increase of the same magnitude, but this conclusion needs to take into account the nature and extent of the contaminants and the wash temperatures required.

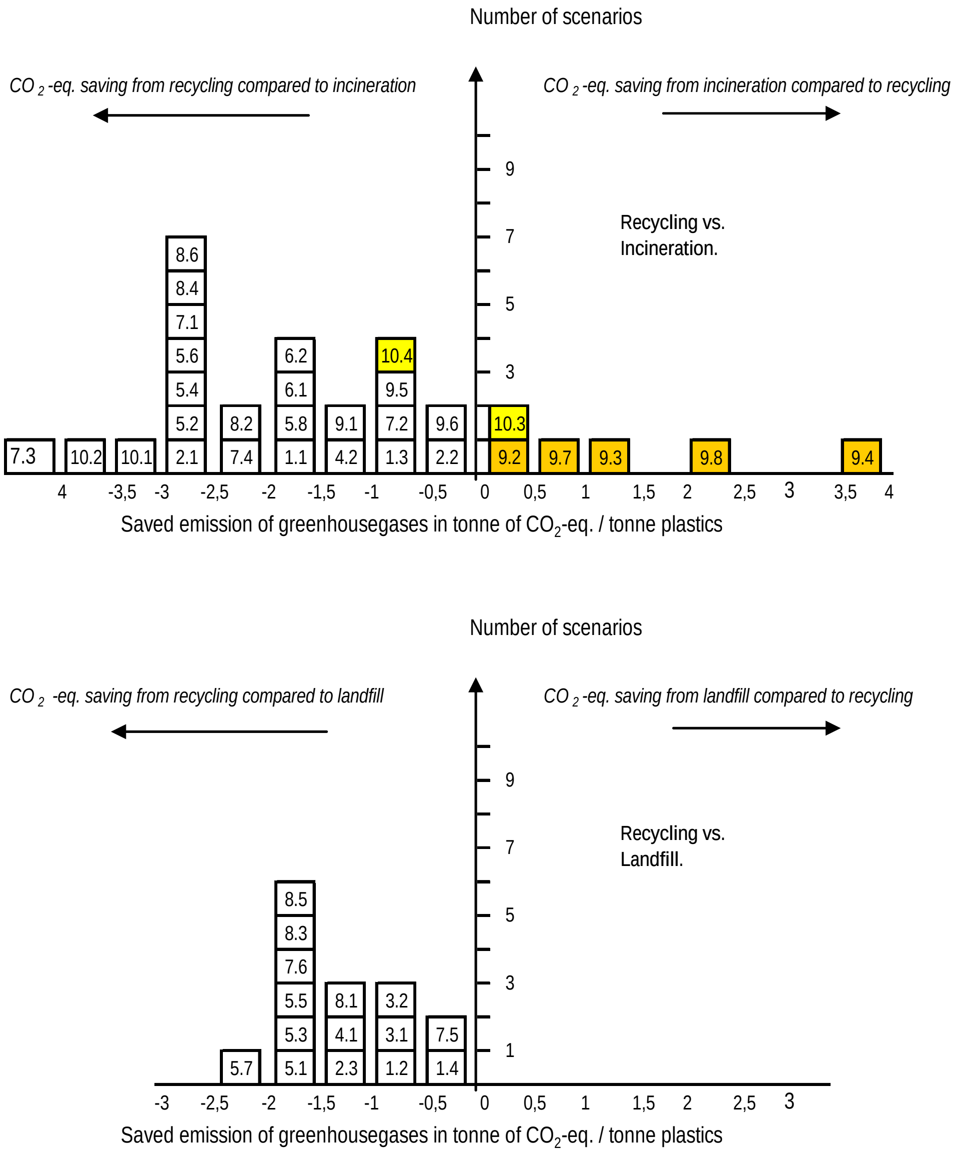


Figure 3.17 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the saved emission of greenhouse gases from recycling vs. incineration and recycling vs. landfill respectively. A negative value (the left side of the diagrams) means that recycling causes a saving compared to incineration or landfill. For legends: see Figure 3.13

3.5 Aluminium

3.5.1 Main Findings

An overview of the 11 in-depth reviewed studies is presented in **Table 3.9**, including all 20 scenarios. The overall conclusion on environmental impact/preference was similar in most scenarios, recycling being the preferred waste management option in 17 out of 20 scenarios, with 3 in favour of incineration and none concluding landfilling to be the preferable disposal option for aluminium.

Table 3.9 Summary of aluminium LCAs reviewed

Study no.	**Waste material studied**	**Country/ region**	**Scenario no.**	**Waste handling comparison**	**Concluded environmental preference**		
					Recycling	**Incineration**	**Landfill**
AL 1	Alu cans	Denmark	1.1	Recycling vs. Incineration	**X**		(n.a.)
AL 2	Alu cans	Sweden	2.1	Recycling vs. Landfill	**X**	(n.a.)	
			2.2	Recycling vs. Incineration	**X**		(n.a.)
			2.3	Incineration vs. Landfill	(n.a.)	**X**	
			2.4*	Incineration vs. Landfill	(n.a.)	**X**	
AL 3	Alu cans	USA	3.1	Recycling vs. Landfill	**X**	(n.a.)	
			3.2	Recycling vs. Incineration	**X**		(n.a.)
AL 4	House-hold packaging	Europe	4.1**	Recycling vs. Incineration	**X**		(n.a.)
			4.2**	Recycling vs. Incineration	**X**		(n.a.)
			4.3**	Recycling vs. Incineration		**X**	(n.a.)
			4.4**	Recycling vs. Incineration	**X**		(n.a.)
AL 5	Alu packaging	Australia	5.1	Recycling vs. Landfill	**X**	(n.a.)	
AL 6	Alu cans	Europe	6.1	Recycling vs. Landfill	**X**	(n.a.)	
			6.2	Recycling vs. Incineration	**X**		(n.a.)
AL 7	Alu in municipal waste	Europe	7.1	Recycling vs. Landfill	**X**	(n.a.)	
AL 8	Alu cans	Denmark	8.1***	Recycling vs. Incineration	**X**		(n.a.)
AL 9	Product-indepen-dent	UK	9.1	Recycling vs. Incineration	**X**		(n.a.)
			9.2	Recycling vs. Landfill	**X**	(n.a.)	
AL 10	Alu cans	Germany	10.1****	Recycling vs. Incineration	**X**		(n.a.)
AL 11	Alu in municipal waste	UK	11.1	Recycling vs. Landfill	**X**	(n.a.)	

* 2.4 is based on input material 75% recycled and 25% virgin aluminium. ** The scenarios combine different optimistic and pessimistic energy recovery scenarios. *** Preference based on energy requirements described in the study. **** Preference based on scenarios described in sensitivity analysis of the study. n.a. = “not applicable”

Table 3.10 gives an overview of the extent to which the different studies have considered the 16 key system boundary issues described in **Section 2.3.1**. Overall, most of the reviewed aluminium studies were relatively transparent regarding the description of these system boundary issues. **Table 3.10** indicates the extent to which issues were considered and documented. Details of the these boundary conditions for each study are documented in the review matrices in **Appendix 5**.

Table 3.10 Overview of the extent to which the 16 key system boundary issues were considered in the aluminium LCA studies analysed

Code	System boundary conditions		Number of studies	% of the studies that consider in any of the scenarios the given boundary condition
Virgin material production				
1	Material marginal	Considered	10	91%
		No Inf.	1	-
2	Electricity marginal:	Considered	11	100%
	which?	No Inf.	0	-
3	Steam marginal:	Considered	6	55%
	which?	No Inf.	5	-
4	Co-products dealt with?	Yes / N.a.	1	9%
		No	10	-
Secondary material production				
5	Material marginal	Considered	10	91%
		No Inf.	1	-
6	Electricity marginal:	Considered	11	100%
	which?	No Inf.	0	-
7	Steam marginal:	Considered	6	55%
	which?	No Inf.	5	-
8	Co-products dealt with?	Yes / N.a.	2	18%
		No	9	-
Material recovery				
9	Product dependent material	Yes	6	55%
	recovery included?	No	5	-
10	Type of product dependent	Considered/ N.a.	9	82%
	material recovery	No Inf.		-
Material disposal				
11	Disposal comparison	Considered	11	100%
		No Inf.	-	-
12	Emissions from landfill	Considered	8	73%
	included?	No Inf.	3	-
13	Energy from incineration	Considered/ N.a.	11	100%
	substitutes heat?	No Inf.	0	-
14	Energy from incineration	Considered/ N.a.	11	100%
	substitutes electricity?	No Inf.	0	-
15	Alternative use of incineration	Considered/ N.a.	2	18%
	capacity included?	No Inf.	9	-
16	In which ratio does recycled	Considered	7	64%
	material substitute virgin material? (1:1 or 1:0.5 or other)	No Inf.	4	-

The review identified a number of system boundary issues which were treated in a less than transparent way, especially the assumed steam marginals for the virgin (issue 3 in Table 3.10) and recycled material (issue 7) and the treatment of co-products at both stages (issues 4 and 8). Also, the substitution ratio of recycled material to virgin material (issue 16) was not described in about a third of the reviewed studies.

3.5.2 Aluminium: Recycling vs. Incineration

Figure 3.18 illustrates that recycling was more favourable than incineration across almost all the scenarios and environmental impact categories considered, in spite of variations made in the underlying system assumptions.

There was only one comparative scenario (4.3) that deviated from this general trend. This 'outlier' scenario compared a pessimistic recycling scenario with a scenario of optimistic incineration in which aluminium was recycled post-incineration. The scenario assumed a very high recovery rate for the extraction of aluminium from the slag after incineration (80% recovery), simultaneously with a poor recycling rate. This assumption, however, cannot be regarded as either typical or representative.

The conclusion that recycling was the most favourable option compared with incineration was based on 7 scenarios from 4 different studies comprising the whole life cycle. All of these studies focussed on packaging materials and on the comparison of one packaging material against another. None of these studies were designed specifically for the comparison of waste management options for aluminium. It was, however, possible to calculate the relative difference of the impact from recycling vs. incineration as captured in **Figure 3.18**.

The conclusions from these studies were supported by 4 scenarios from 4 LCA-like studies that only focussed on the end-of-life phase and/or LCA studies which did not allow the quantification of results (especially study AL-9, which did not state a result for each scenario alone but only relative differences between them). The 4 LCA-like studies are represented by the hatched boxes on the left side of the diagrams in Figures 4.1 to 4.3.

3.5.3 Aluminium: Recycling vs. Landfill

Figure 3.19 illustrates that recycling was clearly more favourable than landfill in all the scenarios and all the environmental impact categories considered.

This conclusion was based on 3 scenarios from 3 different studies comprising the whole life cycle. Two of these studies focussed on packaging materials and on the comparison of one packaging material against the other. Only the third study (AL-11) had the main objective of comparing waste management options for aluminium. As with the recycling versus incineration scenarios, it was possible to calculate the relative difference of the impact from recycling vs. landfill as illustrated in **Figure 3.19**.

The conclusions from these studies were again supported by more qualitative evidence from 5 LCA-like studies which focussed on the end-of-life phase and/or LCA studies which did not allow the quantification of results (again, especially study AL-9). The 5 scenarios derived from these studies are represented by the hatched boxes on the left side of the diagrams in Figure 3.19. Although these studies didn't supply quantitative results, they were found to distinctly in favour of recycling when compared to landfill in their conclusions.

Though a smaller number of scenarios were presented for this comparison the result was clearly in favour of recycling, as values for all scenarios in all impact categories were in the interval between -100 % and -75 % on the left hand side of the diagrams.

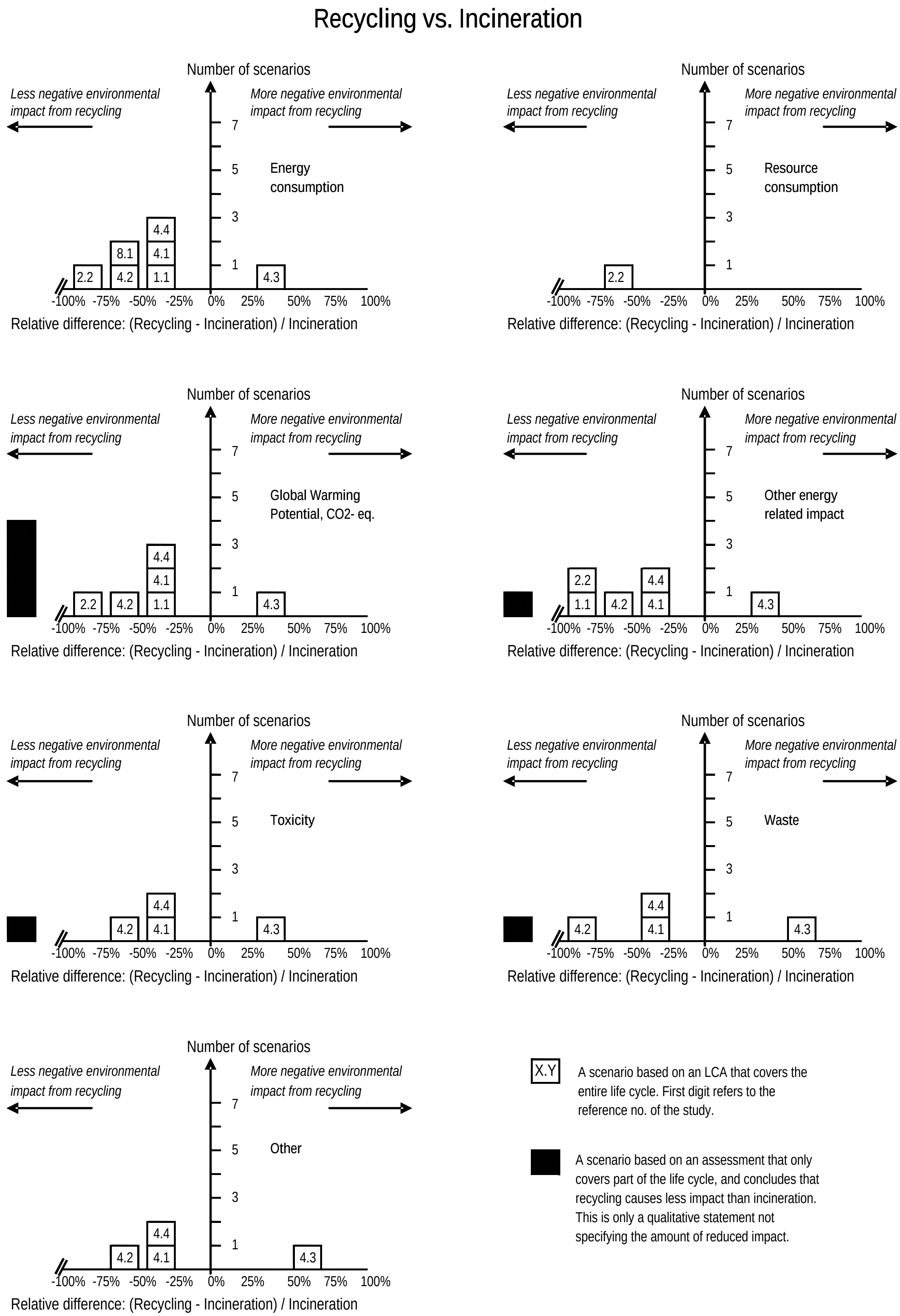


Figure 3.18 *Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. incineration. A negative value means that recycling causes less impact than incineration*

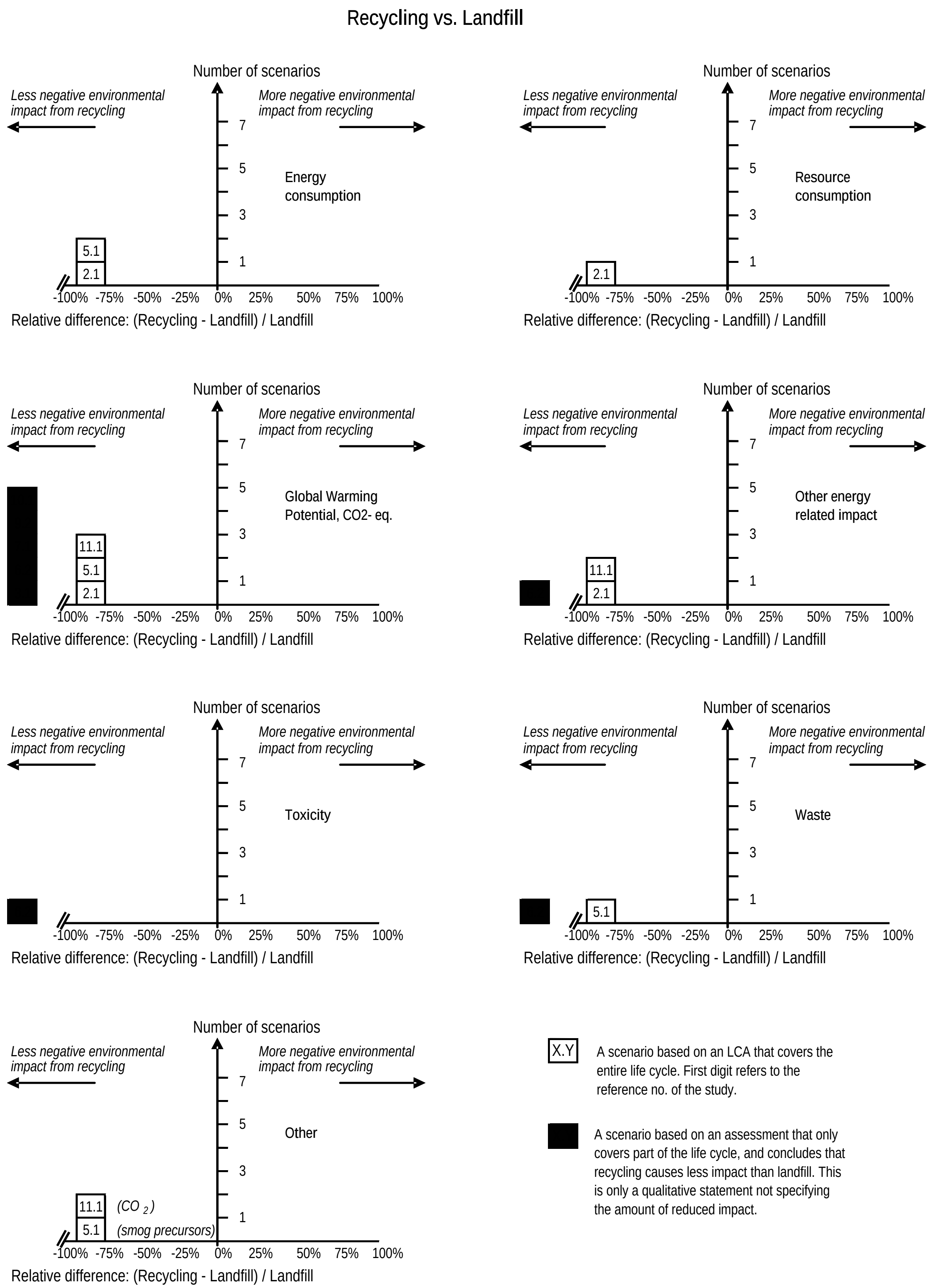


Figure 3.19 *Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. landfilling. A negative value means that recycling causes less impact than landfilling*

.5.4 Aluminium: Incineration vs. Landfill

Figure 3.20 illustrates the comparison of incineration versus landfill. It was only possible to identify 4 scenarios from one study (AL-2) addressing this particular comparison, and the comparison was only made for 4 impact categories. The diagrams in Figure 3.20 indicate a conclusion that incineration is slightly in favour of landfill. This indication can be supported by Figures 3.18 and 3.19.

Comparing these figures, a cautious conclusion can be drawn that the difference between recycling and landfill is more distinct than the difference between recycling and incineration. By cross-referencing these two conclusions it might be concluded that incineration causes less environmental impact than landfill. Thus, a decreasing magnitude of environmental impacts caused in the sequence “aluminium landfilling” > “incineration” > “recycling” could be stated.

However, it should be emphasised that this conclusion is subject to a great deal of uncertainty, and it will probably be very sensitive to variation in local boundary conditions.

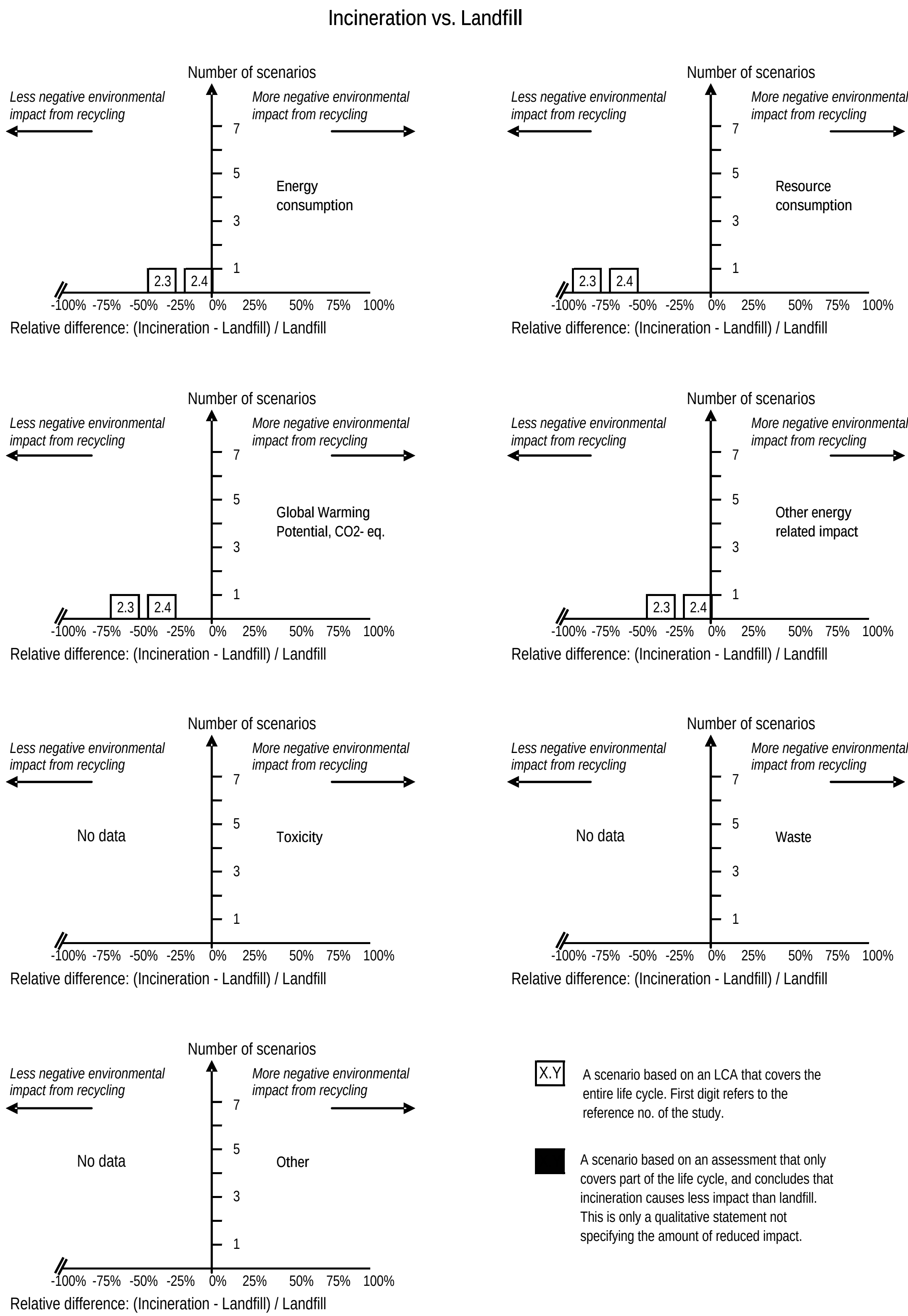


Figure 3.20 *Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from incineration vs. landfilling. A negative value means that incineration causes less impact than landfilling*

3.5.5 Aluminium: Greenhouse gas savings

Figure 3.21 displays the results from the LCA studies reviewed on the saved emission of greenhouse gases achieved by recycling, as compared to incineration or landfilling. Figure 3.21 contains no hatched scenarios as the results represent direct quantitative statements from the reviewed studies.

With the exception of the outlier scenario Al-4.3 already mentioned, all studies indicated that there was a greenhouse gas emissions saving through aluminium recycling, which was typically between 5 and 10 tons CO_2-equivalents/tonne aluminium compared with incineration and also between 5 and 10 ton CO_2-equivalents/tonne aluminium compared with the landfilling of aluminium.

Regarding greenhouse gas savings of recycling compared to landfilling, an extreme value of almost 51 tonnes saved CO_2-equivalents/tonne aluminium was derived from scenario AL-11.1 (this value was thoroughly checked by the review team). Based on the fact that most other scenarios resulted in substantially lower savings in this category, this scenario was considered to be a clear outlier.

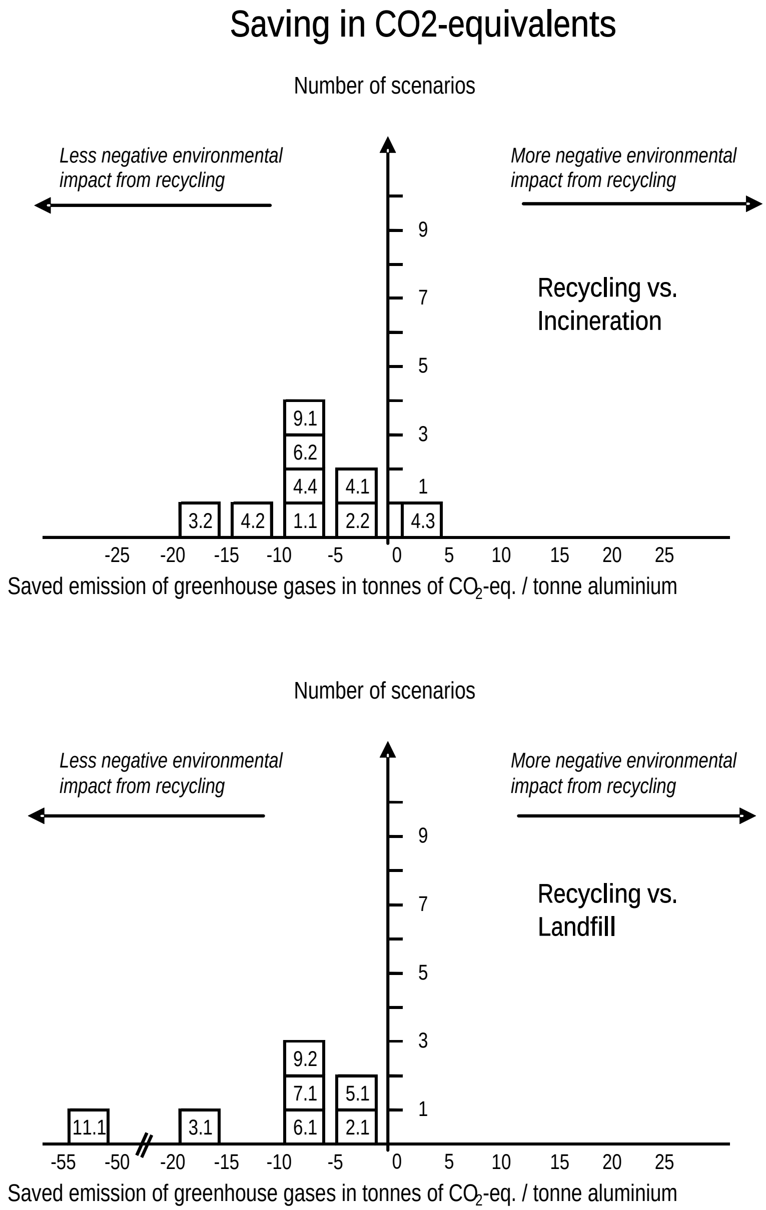


Figure 3.21 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the difference in global warming potential impact from recycling vs. incineration and landfilling. A negative value means that recycling causes less impact than incineration/landfilling

3.6 Steel ~ Results

3.6.1 Main Findings

The overall conclusion from the 9 steel studies reviewed was that the recycling of steel has a lower environmental impact than the alternatives of incineration or landfilling, with energy consumption being a decisive parameter (**Table 3.11**). The advantages of recycling held true across all of the environmental impact categories included in the studies.

Table 3.11 Summary of steel LCAs reviewed

Study no.	Waste material studied	Country/ region	Scenario no.	Waste handling comparison	Concluded environmental preference		
					Recycling	Incineration	Landfill
ST 1	Steel packaging	UK	1.1	Recycling vs. landfill	X	(n.a.)	
ST 2	Steel packaging	Sweden	2.1	Recycling vs. landfill	X	(n.a.)	
			2.2	Recycling vs. landfill	X	(n.a.)	
ST 3	Steel tin plate	Australia	3.1	Recycling vs. landfill	X	(n.a.)	
ST 4	Steel in MSW	Spain	4.1	Recycling vs. landfill	X	(n.a.)	
ST 5	Steel tin plate packaging	Denmark	5.1	Recycling vs. incineration	X		(n.a.)
ST 6	Steel cans	USA	6.1	Recycling vs. landfill	X	(n.a.)	
			6.2	Recycling vs. incineration	X		(n.a.)
ST 7	Steel in MSW	Europe	7.1	Recycling vs. incineration	X		(n.a.)
			7.2	Recycling vs. landfill	X	(n.a.)	
ST 8	Steel packaging	Europe	8.1	Recycling vs. incineration	X		(n.a.)
			8.2	Recycling vs. incineration	X		(n.a.)
			8.3	Recycling vs. incineration		X	(n.a.)
			8.4	Recycling vs. incineration	X		(n.a.)
ST 9	Steel packaging	Europe	9.1	Recycling vs. landfill	X		(n.a.)
			9.2	Recycling vs. incineration	X	(n.a.)	
			9.3	Recycling vs. incineration	X	(n.a.)	
			9.4	Recycling vs. landfill	X		(n.a.)
			9.5	Recycling vs. incineration	X	(n.a.)	
			9.6	Recycling vs. incineration	X	(n.a.)	

In terms of the 16 key system boundaries, the overall conclusion was that the reviewed studies handled these well (**Table 3.12**), with the exception of the inclusion of the environmental effects of by-products. The low proportion of studies that dealt with issue 15 (incineration capacity release) was not considered to be crucial in the case of steel, given its almost zero calorific value.

Table 3.12 Overview of the extent to which the 16 key system boundary issues were considered in the steel LCA studies analysed

Code	System boundary conditions		Number of studies	% of the studies that consider in any of the scenarios the given boundary condition
Virgin material production				
1	Material marginal	Considered	9	100%
		No Inf.	0	-
2	Electricity marginal: which?	Considered	9	100%
		No Inf.	0	-
3	Steam marginal: which?	Considered	5	56%
		No Inf.	4	-
4	Co-products dealt with?	Yes/N.a.	0	0%
		No	9	-
Secondary material production				
5	Material marginal	Considered	8	89%
		No Inf.	1	-
6	Electricity marginal: which?	Considered	9	100%
		No Inf.	0	-
7	Steam marginal: which?	Considered	5	56%
		No Inf.	4	-
8	Co-products dealt with?	Yes/N.a.	1	11%
		No	8	-
Material recovery				
9	Product dependent material recovery included?	Yes	6	67%
		No	3	-
10	Type of product dependent material recovery	Considered/N.a.	6	67%
		No Inf.	3	-
Material disposal				
11	Disposal comparison	Considered	9	100%
		No Inf.	-	-
12	Emissions from landfill included?	Considered	6	67%
		No Inf.	3	-
13	Energy from incineration substitutes heat?	Considered/N.a.	9	100%
		No Inf.	0	-
14	Energy from incineration substitutes electricity?	Considered/N.a.	9	100%
		No Inf.	0	-
15	Alternative use of incineration capacity included?	Considered/N.a.	1	11%
		No Inf.	8	-
16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other)	Considered	5	56%
		No Inf.	4	-

Even though the existing LCAs on steel disposal were of a generally good quality, there were aspects of transparency in the justification of the assumptions made in them that were clearly insufficient. The main problems were associated with:

- The description of the interactions with the energy system;
- The description of the by-products generated (such as slag from steel furnaces), and whether they substitute or not other products (such as cement);
- The description of the treatment of the slag generated by incineration of steel: is it recovered using magnetic devices? Is it landfilled?

The assumptions that had the highest influence on the results were those related to the interdependency of the steel waste handling system with the energy system of the surrounding technosphere, including:

- The type of energy used for manufacture of primary steel: fossil, biomass, or other?
- The type of energy used for manufacture of secondary steel from recycled scrap fossil, hydropower, nuclear, biomass, or other?

The treatment of marginal energy sources was particularly significant to the steel system comparisons, given that primary steel production, an industry very dependent on the use of coal, is currently being transferred to countries where this resource is cheap. Had the marginal energy of those countries been included within the LCAs? Similarly, secondary steel produced from scrap is electricity intensive, requiring that the marginal energy sources for power in the production site are correctly characterised.

An issue closely related to energy consumption and substitution is the destination of the co-products generated during steel production, in particular furnace slag. Some studies postulated that furnace slag can substitute cement minerals in cement production. Consequently, the steel production system could receive credit for the energy and natural resources saved in the production of an equivalent quantity of cement. This issue was discussed in some of the non-reviewed LCAs screened during this project, but was not reported quantitatively in any of the reviewed LCAs.

As with aluminium, this review showed that the assumptions made by a study about the effectiveness of steel reclamation and recycling from incineration slag are very relevant for the outcome of a steel LCA. However, the studies that included this factor did not provide sufficient evidence of the sensitivity of this assumption.

Studies looking more thoroughly at the issues of incineration slag reclamation and furnace slag including sensitivity assessments of the assumptions, are currently lacking.

Different steel types (carbon, tinplate, stainless, special steel alloys) have different lifecycles, are used in different products, and result in different scrap categories of different quality. The effect that these differences may have on the environmental impact of recycling as compared with alternative disposal routes was not sufficiently clarified in the reviewed studies. The reviewed mostly featured steel packaging products (beverage cans, tinned food), and their use in an unspecified steel or tinplate composition. Therefore, the studies have not revealed the significance that separation technologies for more complex products may have. Systems for products requiring more sorting and shredding and the environmental feasibility of steel recycling in such cases were not represented in existing studies and would be additional candidates for further study.

The above-mentioned issues could be the subject of sensitivity analyses, where targeted LCA modelling exercises are carried out, exploring the significance of the specific assumptions. The International Iron and Steel Institute (IISI) has prepared a high-quality inventory database, which includes many steel types from many steelworks world-wide, and is available to experts. This database could easily be used for such an exercise in order to complete the knowledge gaps still remaining for the iron and steel system.

3.6.2 Steel: Recycling vs. Incineration

Figure 3.22 illustrates that recycling is more favourable than incineration in 14 out of the 21 scenarios included, that is, the majority of scenarios are on the left hand side of the diagrams. However, a closer look at the 7 scenarios where incineration was more favourable than recycling (to the right hand side) reveals that 5 of them are from the same scenario, ST-8.3, which is a clear outlier compared with the results of the other scenarios.

The outlier, scenario ST-8.3 is a scenario from the packaging waste study by RDC-Coopers and Lybrand, 1997 (see also **Appendix 5**, study ST-8), which compares a very inefficient packaging waste recycling option (collection in low-density areas, long transport distances to the sorting center and to the landfill, half-empty lorries, low content of steel in waste) to a very efficient incineration system (collection in high-density areas, short transport distances to the sorting center and to the incinerator and the landfill, full-loaded lorries, high content of steel in waste, high energy recovery rate in incinerators, 90% steel recovery from slag). The incineration scenario was thus allocated all the potential benefits from such systems, whereas the recycling scenario received all of the potential drawbacks.

The study did not indicate what the allocation procedure had been for the energy generated by landfill, and whether it had been partly allocated to steel (with no positive heating value!) following an allocation by weight or not.

The results from scenario ST-8.3 should therefore to be considered as a theoretical exercise of interest for modelling purposes but not from a real life waste management perspective. Likewise results from ST-8.2 from the same study, which was based on the opposite set of assumptions to those of scenario ST-8.3, (an efficient recycling system versus an inefficient incineration system) should be subject of the same caveats.

The conclusion from **Figure 3.22** was that for most scenarios and most impact categories included in the studies, recycling was preferable to incineration.

In addition to this, 4 scenarios (shaded in Figure 3.22) provided quantitative information in favour of recycling, but these scenarios have not been plotted in the quantitative area of the figure due to the percentage presentation form chosen.

It is important to comment at this point that the conclusions from **Figure 3.22** were very dependent on the results from two comprehensive studies: ST-8 by RDC-Coopers and Lybrand (1997), and ST-9, by RDC and Pira (2005). As both studies included the same co-author and the same study goal of supporting the EU Commission's packaging policy, it is expected that they used similar data sources and approaches to system description. It would therefore would have been valuable to have contrasted the results from these two studies with those from other, more dissimilar studies.

The best-represented impact categories in the comparisons of the studied LCAs were energy consumption and the related impacts of global warming, acidification, and nutrient enrichment. Some studies also gave values for toxicity impacts and waste impacts. No study reported directly on resource consumption, however, an indirect expression of energy resources consumption is, logically, the energy consumption indicator.

Except for two scenarios (ST-6.1 and ST-7.1), all scenarios stem from LCA studies on packaging, and therefore not from LCAs specifically designed for the analysis the life cycle and disposal options for steel.

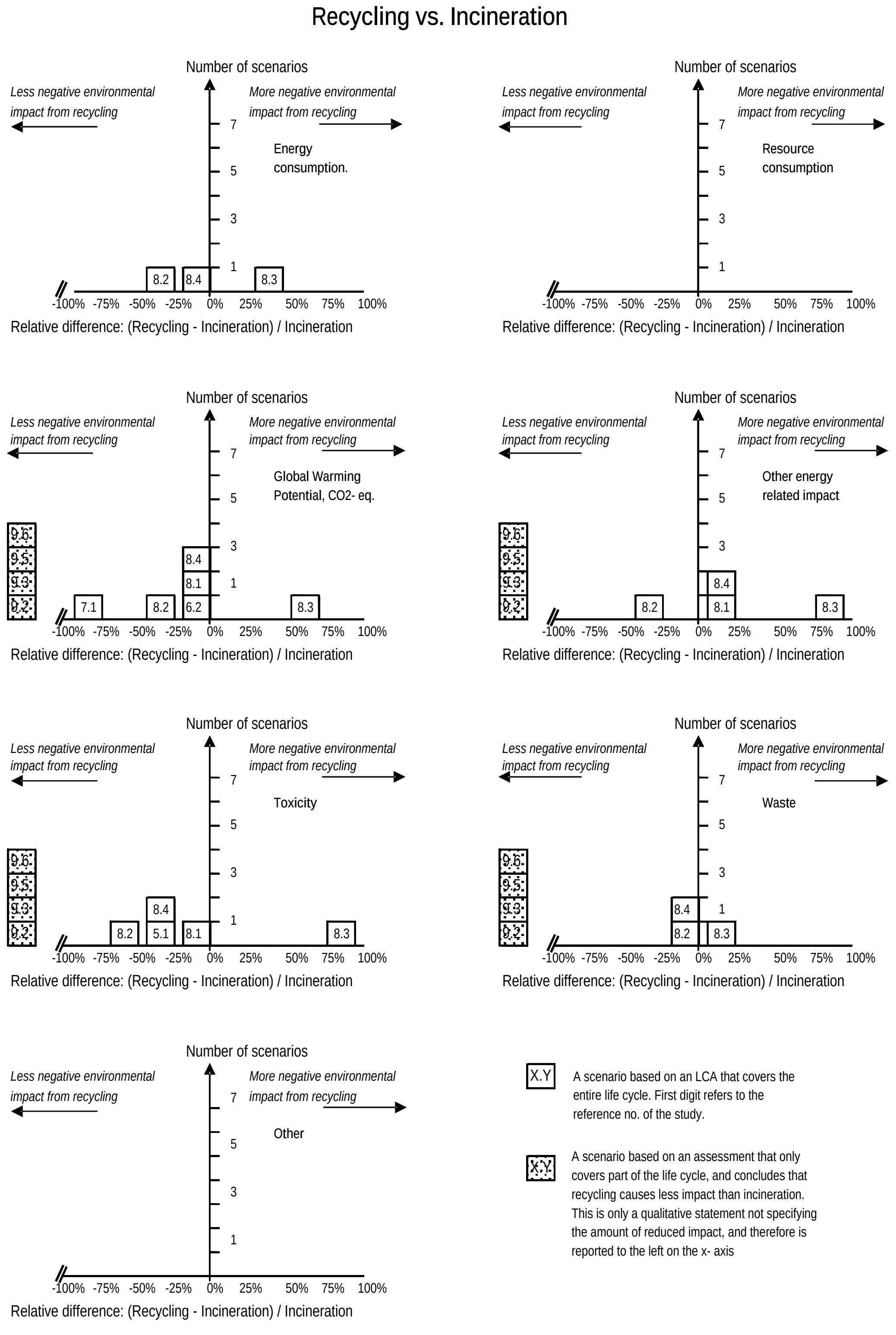


Figure 3.22 Frequency functions of the distribution of results from the scenarios of the reviewed studies, showing the relative difference in impact from recycling vs. incineration. A negative value means that recycling causes less impact than incineration.

3.6.3 Steel: Recycling vs. Landfill

Figure 3.23 illustrates results from the comparisons of recycling and landfilling. The overwhelming conclusion was that recycling was clearly more favourable than landfill in all but one of the scenarios, and all but one (nutrient enrichment) of the environmental impact categories considered.

The results of the comparison between recycling and landfilling were even clearer than recycling versus incineration. This was somehow counter-intuitive, because incineration is a process which does not obtain any benefit from steel waste, on the contrary, it uses heat to warm up steel slag, heat which is lost, or at best partially reclaimed, when the slag cools down. Two possible explanations for this are:

(1) That some of the energy derived from waste incineration was allocated to steel, based on a weight or volume factor for steel in the waste stream. This assumption, if in place, is essentially wrong, but is frequently seen in some LCAs.

(2) That steel was recovered from slag with a high efficiency, and its energy content also was efficiently reclaimed. Under such circumstances, incineration would be just an 'intermediate' steel waste treatment, not followed by landfilling but instead by recycling. If steel waste from slag had been credited with the benefits of recycling, then it could be an explaination for incineration, which in reality is post-incineration recycling, resulting in lower impacts than landfilling.

Many studies were not transparent on these two assumptions, and it was therefore not possible to unmask in all the studies' background material the reasons why incineration was such a favourable handling option for a material which does not burn.

Most of the impact categories contained in the reviewed studies were related to energy consumption. This is one of the possible explanations of why the environmental benefits of recycling have a very similar relative magnitude expressed in percentages in most of the impact categories reported in the studies.

Most of the plotted studies were multi-material packaging waste studies. Only one of the studies (Craighill *et al.,* 1996) had the specific objective of comparing waste management options for steel. Its results generally coincided with those from the packaging-oriented studies.

The conclusions from the studies were supported by the results from scenarios ST-9.1 and ST-9.4, represented by the hatched boxes in the left side of the diagrams in **Figure 3.23**. The results from these studies, still being quantitative, could not be represented in the percentage format common to the other studies due to the lack of an absolute reference (these studies reported only the net difference or net saving between recycling and the alternative).

3.6.4 Steel: Incineration vs. Landfill

None of the selected studies on steel compared these two handling options. If needed, a relative, qualitative comparison can be done indirectly by observing in Figures 3.22 and 3.23 that the environmental impacts from steel waste handing were, in the LCA studies analysed, greatest for landfilling, flowed by incineration and least in the case of recycling.

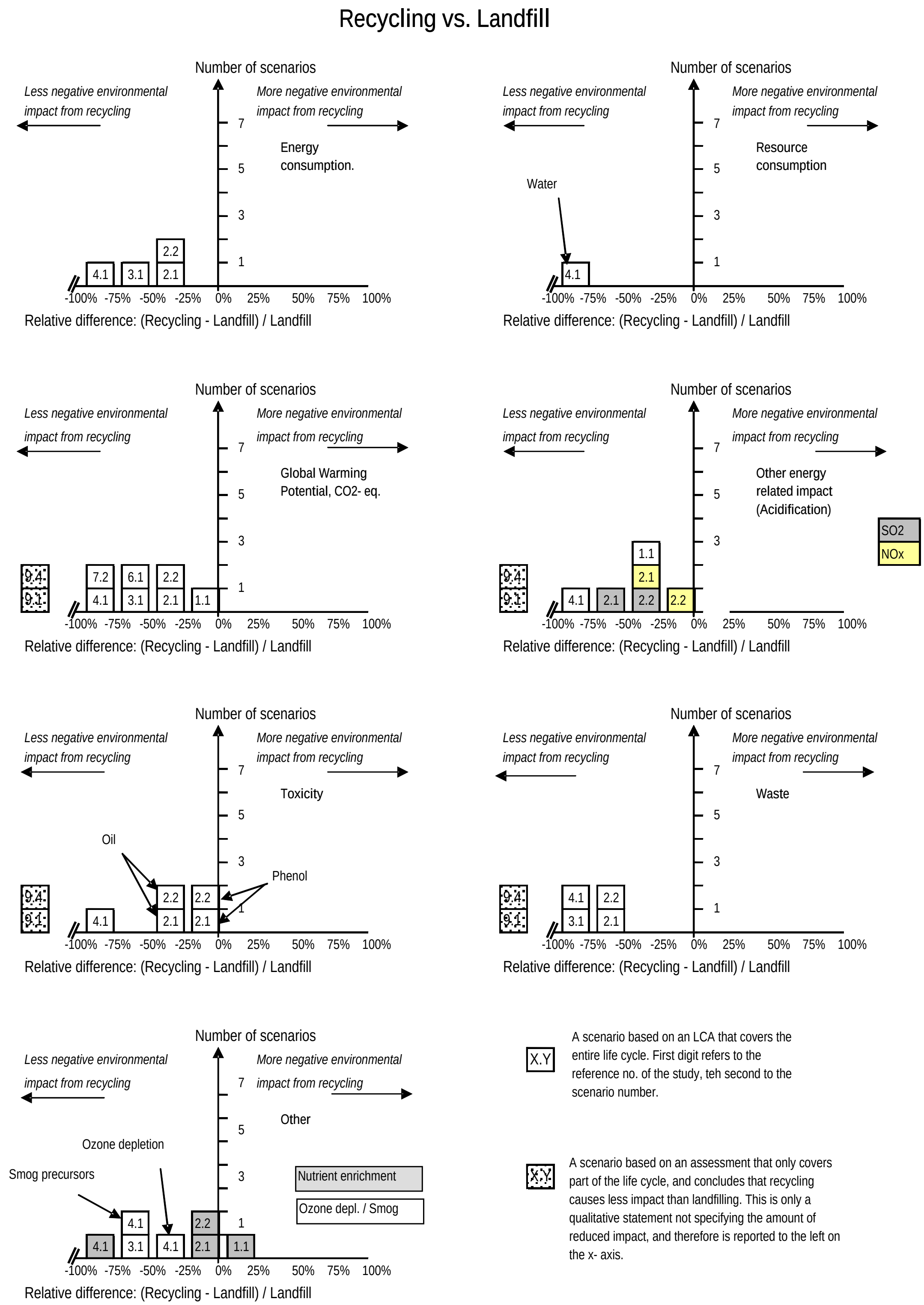
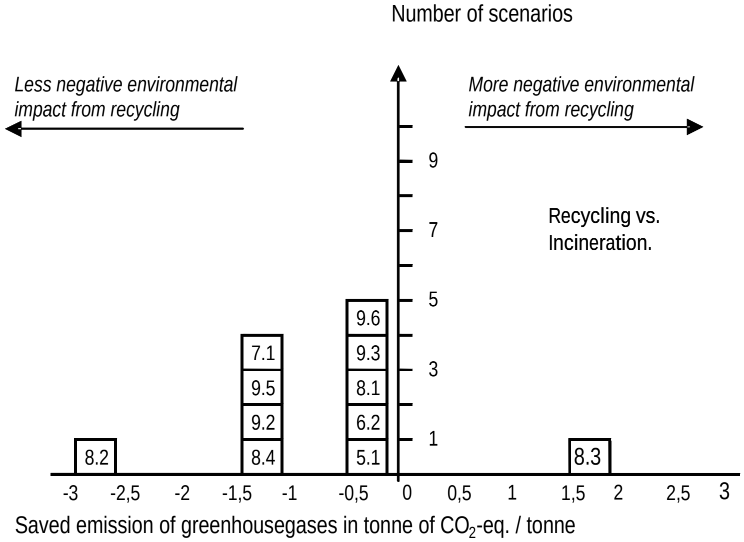


Figure 3.23 Frequency functions of the distribution of results from the scenarios of the reviewed studies, showing the relative difference in impact from recycling vs. landfill. A negative value means that recycling causes less impact than landfill.

3.6.5 Steel: Greenhouse gas savings

The saved emissions of greenhouse gases achieved by recycling, as compared with landfilling or incineration are shown in **Figure 3.24**.

With the exception of the mentioned outlier scenario ST-8.3, all studies indicated greenhouse gas emissions savings through recycling, which on average were 0.94 kg CO_2-equivalents/kg steel compared with incineration and 1.33 kg CO_2-equivalents/kg steel compared with landfilling.



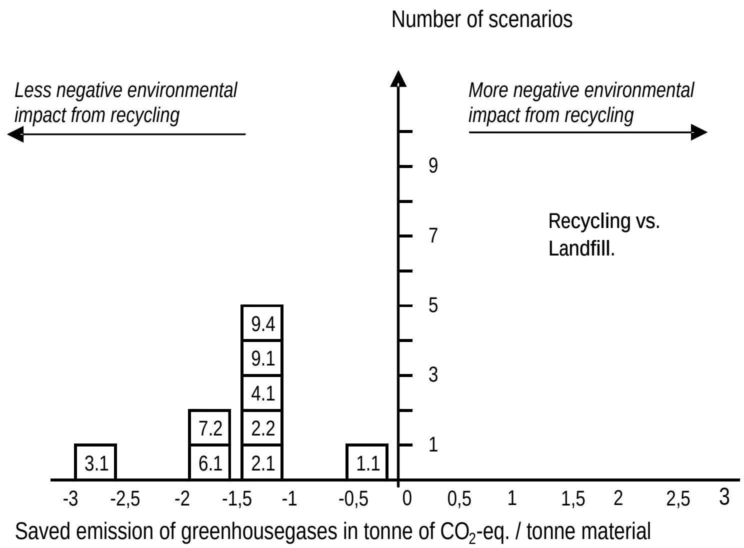


Figure 3.24 Frequency functions of the distribution of results from the scenarios of the reviewed studies showing the saved emission of greenhouse gases from recycling vs. incineration and recycling vs. landfill respectively. A negative value (the left side of the diagrams) means that recycling causes a saving compared to incineration or landfill.

3.7 Wood ~ Results

3.7.1 Main Findings

The evaluation process led to only 3 studies that fulfilled the selection criteria. Based on the comprehensive literature search that identified 29 different studies, these studies are believed to represent the best selection of existing literature.

A total of 7 scenarios comparing the incineration and landfill options for wood waste were included in the detailed review. The geographical coverage of the studies was confined to Germany, Austria, Canada and the Nordic countries (Norway, Sweden and Finland).
An overview of the reviewed studies is presented in **Table 3.13** below, including the country/region covered by the study, the wood type and the product in which the wood waste arose, the waste handling scenarios being compared and the overall verdict on the environmental preference from each scenario. In all scenarios, the incineration of wood waste was found to be preferable to landfill.

No studies were identified that included either wood recycling for material recovery or wood re-use.

Table 3.13 Summary of wood LCAs reviewed

Study no.	Waste material studied	Country/ region	Scenario no.	Waste handling comparison	Concluded environmental preference	
					Incineration	Landfill
1	Laminated wood in roof construction	Norway	1.1	Incineration vs. landfill	X	
			1.2	Incineration vs. landfill	X	
2	Recovered wood from demolition	Sweden and Finland	2.1	Incineration vs. landfill	X	
			2.2	Incineration vs. landfill	X	
3	Recovered wood from demolition	Germany/ Austria	3.1	Incineration vs. landfill	X	
		Canada	3.2	Incineration vs. landfill	X	
		Germany	3.3	Incineration vs. landfill	X	

As many of the 16 essential boundary issues and assumptions relate to material recycling these issues were not relevant to the three reviewed studies. They have, however, been left in **Table 3.14**, in order to present the holistic overview of which boundary issues are important for assessment of wood waste management.

Table 3.14 Overview of the extent to which the 16 key system boundary issues were considered in the wood LCA studies analysed

Issue no.	System boundary conditions		Number of studies	% of the studies that consider the assumption
Virgin material production				
1	Material marginal: which?	Considered	2	67 %
		No Inf.	1	-
2	Electricity marginal: which?	Considered	3	100 %
		No Inf.	0	-
3	Steam marginal: which?	Considered/n.a.	3	100 %
		No Inf.	0	-
4	Co-products dealt with?	Yes/N.a.	0	0 %
		No	3	-
Secondary material production				
5	Material marginal: which?	Considered/n.a.	3	100 %
		No Inf.	0	-
6	Electricity marginal: which?	Considered/n.a.	3	100 %
		No Inf.	0	-
7	Steam marginal: which?	Considered/n.a.	3	100 %
		No Inf.	0	-
8	Co-products dealt with?	Yes/N.a.	3	100 %
		No	0	-
Material recovery				
9	Product dependent material recovery included?	Yes	0	0 %
		No	3	-
10	Type of product dependent material recovery	Considered/N.a.	3	100 %
		No Inf.	0	-
Material disposal				
11	Disposal comparison	Considered	3	100 %
		No Inf.	0	-
12	Emissions from landfill included?	Considered	2	67 %
		No Inf.	1	-
13	Energy from incineration substitutes heat?	Considered	3	100 %
		No Inf.	0	-
14	Energy from incineration substitutes electricity?	Considered	3	100 %
		No Inf.	0	-
15	Alternative use of incineration capacity included?	Considered	0	0 %
		No Inf.	3	-
16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other)	Considered/N.a.	3	100 %
		No Inf.	0	-

Two of the three studies provided an account of which type of wood was considered to be the marginal virgin wood. All three studies considered which marginal electricity to include and two of the studies assumed fossil fuel based electricity, which is judged to be correct, whereas one study assumed a fraction of the marginal electricity would be derived from Norwegian hydropower, which was probably an incorrect assumption. Steam was judged to be of minor significance in the studied systems, and the studies did not address this issue. None of the studies consider forestry co-products e.g. wood from forestry thinning (which can be utilised for paper making or as a bio fuel) or bark from timber processing. This may be of some significance, although it would not have changed the conclusions of any comparison between incineration and landfilling of wood, only the magnitude of the difference.

None of the studies included operations of wood recovery prior to incineration or landfill. The wood products studied were roof and demolition products in general (rather large wood components) for which any product dependant material recovery is judged to be insignificant.

As only comparative waste management studies were included in the review, naturally all studies were transparent about the comparisons being made. Emissions from landfills were considered by two of the three studies. It is remarkable that the third study did not consider methane emissions from landfill as an important part of the aim of the study was to compare global warming contribution from the compared waste management options. This was a highly significant omission, but it would not have influenced the conclusion: inclusion of methane emissions would only have made the difference between incineration and landfilling greater. All studies addressed the utilisation of heat and electricity from incineration, but none looked at the issue of the alternative use of incineration capacity, i.e. if the incineration capacity released by material recycling could be used to divert other materials away landfill and intio incineration. As the three studies only compared incineration and landfill, this issue was outside the scope of the comparisons made.

The overall conclusion was that the three reviewed studies had successfully addressed the more limited set of system boundary issues covered.

3.7.2 Wood: Incineration vs Landfill

As the **Figure 3.25** illustrates, incineration was reported to be environmentally superior to landfilling in all the scenarios, with an average environmental improvement from incineration of over 100 %. The explanation that incineration can improve the studied impacts of energy consumption and energy related environmental impacts by more than 100 % is that only the consumption and combustion of fossil fuels in the studied systems contributed to these environmental impact categories. Therefore, the fact that wood is used in the energy system, implies savings on fossil fuels and emissions (of e.g. CO_2 and SO_2) from substitutions of fossil fuels that are substantially larger than consumptions/emissions from the wood system itself.

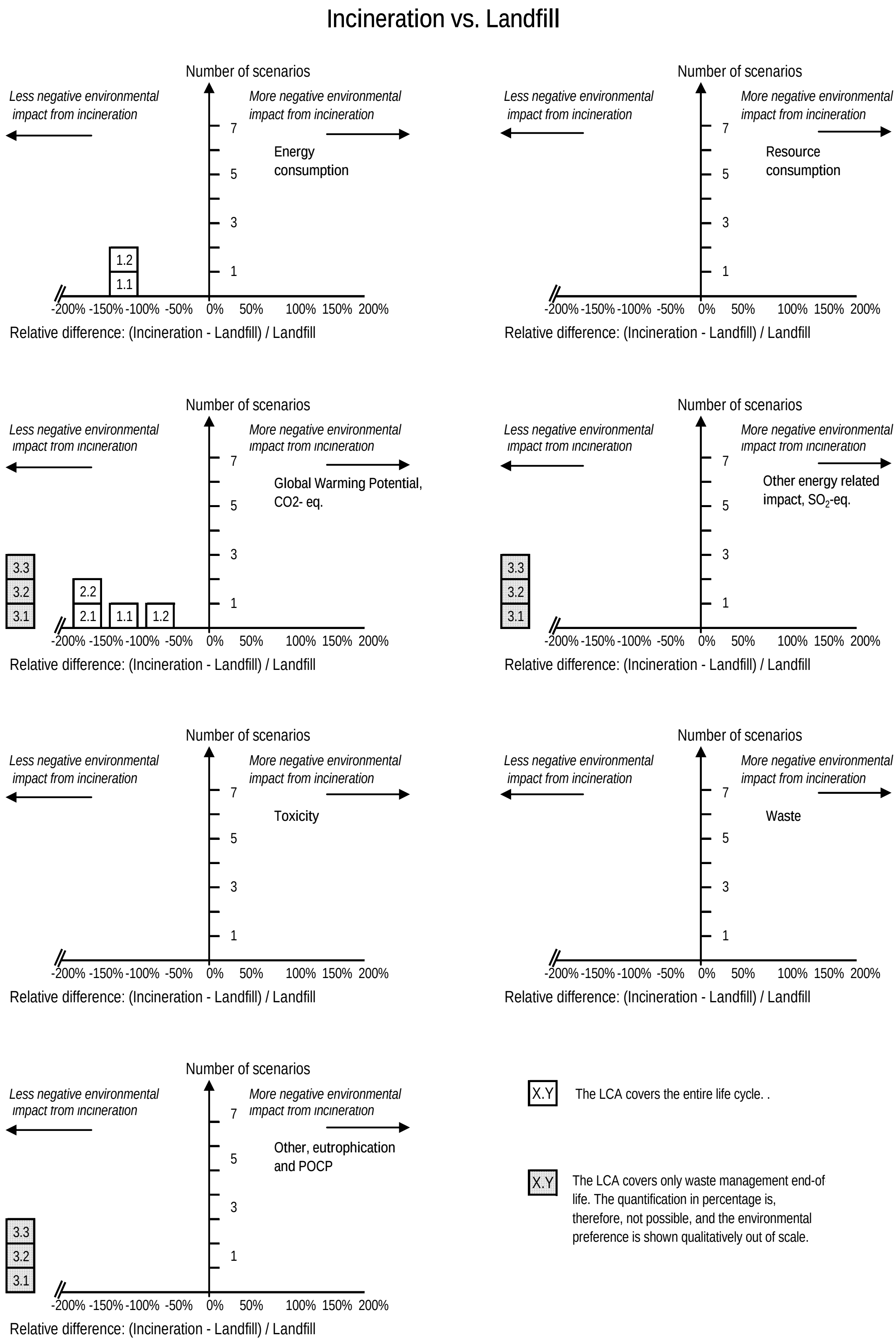


Figure 3.25 Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from incineration vs. landfilling. A negative value means that incineration causes less impact than landfilling

3.7.3 Wood: Greenhouse gas savings

Figure 3.26 shows the net difference between overall emissions of greenhouse gases (GHGs) expressed as CO_2-equivalents. In practice, only CO_2 emissions from the energy systems and methane emission from landfills of wood contributed significantly from the systems studied, as there essentially are no other GHGs in the systems in question. The results attribute an unambiguous advantage of incineration with a net CO_2-eq. saving compared with landfilling ranging from 0.5 to 3.0 tonnes of CO_2-eq. per tonne of wood with an average around 1.5 tonnes CO_2-eq. per tonne of wood.

Saved emission of CO_2-eq.

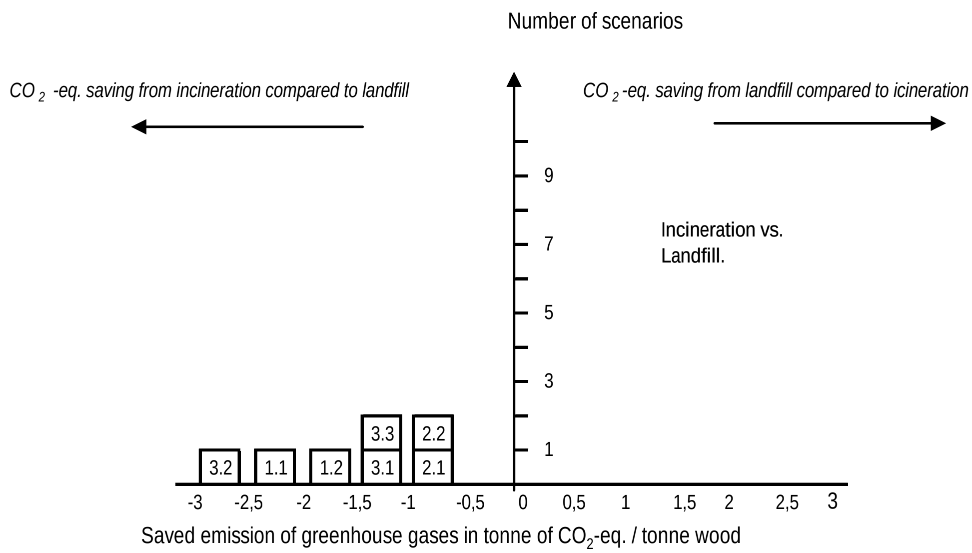


Figure 3.26 Frequency histogram of the distribution of results from the reviewed wood scenarios showing the saved emission of greenhouse gases from incineration vs. landfill. A negative value (the left side of the diagrams) means that incineration causes a saving compared with landfill

3.8 Aggregates ~ Results

3.8.1 Main Findings

In total 24 studies were evaluated of which only 2 fufilled the selection criteria. An overview of both studies is presented in the Table 3.15 below, including all scenarios. As both the waste management comparisons and the overall conclusions on environmental preference were similar in all 6 scenarios, the result was clear cut: recycling of aggregates was the preferred waste management option according to the studies.

Table 3.15 Summary of aggregates LCAs reviewed

Study no.	Waste material studied	Country / region	Scenario no.	Waste handling comparison	Concluded environmental preference	
					Recycling	Landfill
AG-1	Construction and demolition waste	Italy	1.1	Recycling vs. Landfill	X	
			1.2	Recycling vs. Landfill	X	
AG-2	Construction and demolition waste	UK	2.1	Recycling vs. Landfill	X	
			2.2	Recycling vs. Landfill	X	
			2.3	Recycling vs. Landfill	X	
			2.4	Recycling vs. Landfill	X	

Table 3.16 suggests that both studies were relatively transparent regarding the description of their system boundary issues. For instance, both described the type of material marginal for the recycled aggregate material as well as the product-dependant material recovery processes and whether or not recycled material substituted other products (such as virgin bricks or gravel). There were also system boundary issues which were given less transparent treatment, especially the assumed material marginal for the virgin material as well as occurrence and treatment of co-products. Also, in most cases, data from LCA databases on materials have been used without stating further details ~ a recurring issue encountered throughout this review.

The system boundary choice that had the highest influence on the results was that related to the inclusion of avoided upstream processes as a result of recycling: Scenario 1.1 of study AG-1 considered this specifically and identified extreme reductions in environmental impact as consequence. All 5 other scenarios just stated high substitution ratios (issue 16) but stated far lower reductions in environmental impact.

Table 3.16 Overview of the extent to which the 16 key system boundary issues were considered in the aggregates LCA studies analysed

Issue no.	System boundary conditions		No. of studies	% of the studies that consider the issue
Virgin material production				
1	Material marginal	Considered	0	0%
		No Inf.	2	-
2	Electricity marginal: which?	Considered	1	50%
		No Inf.	1	-
3	Steam marginal: which?	Considered	0	0%
		No Inf.	2	-
4	Co-products dealt with?	Yes/ N.a.	0	0%
		No	2	-
Secondary material production				
5	Material marginal	Considered	2	100%
		No Inf.	0	-
6	Electricity marginal: which?	Considered	1	50%
		No Inf.	1	-
7	Steam marginal: which?	Considered	0	0%
		No Inf.	2	-
8	Co-products dealt with?	Yes/ N.a.	0	0%
		No	2	-
Material recovery				
9	Product-dependent material recovery included?	Yes	2	100%
		No	0	-
10	Type of product-dependent material recovery	Considered/ N.a.	2	100%
		No Inf.		-
Material disposal				
11	Disposal comparison	Considered	2	100%
		No Inf.	-	-
12	Emissions from landfill included?	Considered/ N.a.	1	50%
		No Inf.	1	-
13	Energy from incineration substitutes heat?	N.a.	2	100%
		No Inf.	0	-
14	Energy from incineration substitutes electricity?	N.a.	2	100%
		No Inf.	0	-
15	Alternative use of incineration capacity included?	N.a.	2	100%
		No Inf.	0	-
16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other)	Considered	2	100%
		No Inf.	0	-

NOTES: No Inf. = “No information”, N.a. = “Not applicable”

3.8.2 Aggregates: Recycling vs. Landfill

Figure 3.27 illustrates that recycling was clearly favourable to landfill in almost all the scenarios and all the environmental impact categories considered. The only exception was the impact category “other, road transport”, where increased recycling was accompanied by increased transport activity, which outweighed the recycling benefits. This conclusion was based on 6 scenarios from 2 different studies comprising the whole life cycle. Both studies focussed on aggregates waste treatment and the comparison of treatment alternatives against one another.

Study AG-1 stated extremely high reduction potentials relating to recycling. This was based on the - usual - assumption made in the study that recycling may substitute virgin material which not only did not have to be produced but also did not have to be transported, either. However, values quoted for virgin material production were relatively high compared with the other study. The study’s authors mentioned clay brick re-use and a resulting saving of 1,110,000 MJ due to avoided process energy as their major reduction reason in the recycling scenario. Scenario 1.1, which included substitution, therefore produced an extremely favourable result, while scenario 1.2, without substitution, did not.

Study AG-2 also considered substitution but reached far more moderate results. Study AG-2 was considered to be more valuable as calculations were presented in a more consistent way than those contained within study AG-1.

Both studies in fact described mixed scenarios: AG-1 compared a comprehensive recycling system that included a very small portion of landfill with a traditional, almost entirely landfill-based system. AG-2 compared pure landfill with different mixed scenarios of on-site and off-site recycling as well as with pure re-use on-site.

Study AG-1 covered toxicity only qualitatively but concluded with an overall advantage for recycling. The related scenarios 1.1 and 1.2 were therefore included in Figure 4.1 as hatched boxes.

Though a relatively small number of scenarios have been presented for this comparison the result was clearly in favour of recycling, as values for all scenarios in all impact categories except ’other, road transport’ appear on the left hand side of the diagram, with typical values of at least 10-20% and up to 70-80% reduction in environmental impact.

It has to be noted that results presented in AG-1 are not fully consistent with other data in this study and are thus to a certain extent doubtful.

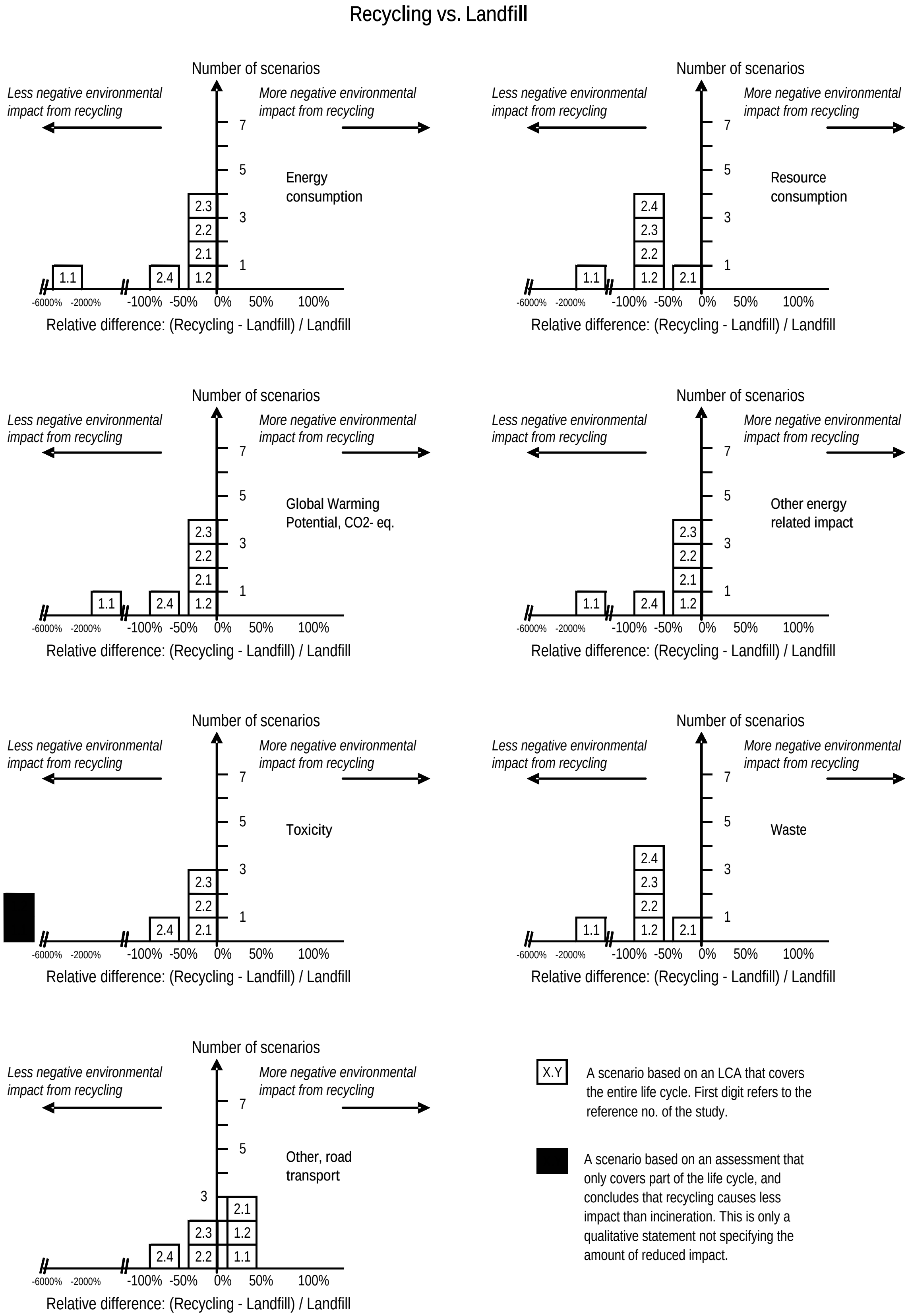


Figure 3.27 *Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. landfilling. A negative value means that recycling causes less impact than landfilling*

3.8.3 Aggregates: Greenhouse gas savings

Figure 3.28 below presents the results from the LCA studies reviewed on the saved emission of greenhouse gases achieved by recycling, as compared to the landfilling of aggregates.

Both studies indicated that there were greenhouse gas emission savings through recycling. With the exception of the outlier scenario AG-1.1, which included substitution of primary material (see previous section) and which stated a saving of 57 tons CO_2-, equivalents/tonne aggregates, typical values were between 1-10 kilograms CO_2-, equivalents/tonne aggregates compared with landfilling. The values in study AG-1 belonging to the outlier scenario (with clay brick re-use) have been thoroughly checked by the review team and approved to be stated correctly from study AG-1. The authors here have attributed the extreme value of scenario 1.1 to data inconsistencies within study AG-1 itself, primarily associated with the poorly described data for clay brick production and certain sums which are stated incorrectly or non-transparently within the presentation of the scenario results (table 5 of the study).

Aggregates

Recycling vs. Landfill

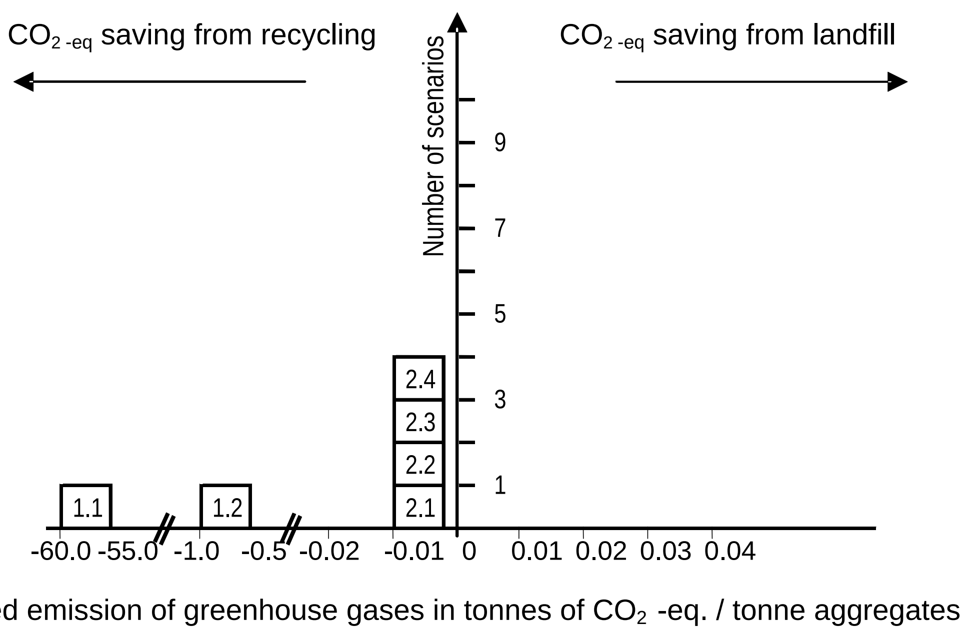


***Figure 3.28** Frequency histograms of the distribution of results from the various scenarios of the reviewed studies showing the relative difference in impact from recycling vs. landfilling. A negative value means that recycling causes less impact than landfilling*

4. Interpretation of results in a UK context

4.1 Introduction

The discussion and interpretation of results presented in the preceding section rely on an understanding of the boundary conditions prevailing in the reviewed studies. These boundary conditions, of course, represent the material production, recovery and waste systems in the regions represented by the studies. These conditions may represent specific technological issues and / or regionally dependent issues. In order to interpret the results and conclusions of the individual material reviews in a United Kingdom context, an analysis has been made of UK conditions, and how these relate to the results of the LCA reviews.

Three main issues were covered in the review of UK conditions:

I. The geographic scope of the markets Are the markets for waste, scrap, recovered material and virgin material global, regional or local and to what extent?
II. The energy and waste systems in general What, if anything, is specific about the UK energy system and the UK waste system in general, and what is the interplay between the UK energy and waste systems?
III. The given material waste management system: What, if anything, is specific about the UK material waste management system?

In this section, these issues are discussed in relation to any UK specific conditions that might potentially influence the interpretation of results from the review reported in Section 3.

4.2 The geographic scope of the markets

Some materials are traded on international and global markets, while for others the markets are more regional or local. This is also the case for scrap and recyclates which are subject to international trade, to a greater or lesser extent.

The extent to which the market is global or regional/local is, amongst other things, governed by a price/weight or price/volume ratio, and whereas some recyclates and scrap types (e.g. paper, steel, aluminium and plastics) are traded within a global market place, others (e.g. glass, wood, aggregates and compost) are traded on a local or national scale, due to the fact that transport and logistics become a decisive cost element.

In general, for globally traded commodities, the LCA should reflect the operations influenced by the choice between waste management options. On a fully global market for materials, the specific UK production of virgin material and specific UK material recovery (e.g. re-melting) would not be influenced by the choice between waste management options in the UK, because these activities are governed by prices on the global material exchange. In a recycling system interacting with a global market, only operations prior to the material entering the market, like collection and pre-processing (e.g. washing), are influenced locally, and often these play a minor role in the overall environmental profile. As any changes in recycling in the UK will influence the specific incineration and/or landfilling systems in UK, and as waste incineration and landfilling do not interplay with any markets outside UK, these UK specific disposal systems will, of course, be influenced even when the materials/scraps concerned are traded globally.

With markets characterised as being local to regional ~ the specific conditions for UK production and recovery are, decisive. Most operations in such systems are, thus, dependent on the specific UK conditions, including production, collection and recovery as well as end disposal at landfills and waste incineration. Among other things, this also means that the specific UK energy supply for production should be addressed. In such markets, the cost of transportation is a barrier for improving logistics and matching the sinks and sources of materials. Higher energy prices allow for overcoming some of this barrier because using recycled materials in production saves energy – so higher energy prices presumably allows for more materials to go back to the point of production.

4.3 The UK energy and waste systems

4.3.1 The systems in general

The UK energy system

As UK material production and recovery are influenced by choice of waste management option, the specific UK energy system providing electricity and heat for these operations has a great significance for comparisons of waste management options today. The essential issue in this respect is that natural gas is the marginal fuel for electricity production in the UK, and that steam production is based on fossil fuels for production in general. On these aspects, therefore, the UK conditions are essentially the same as the conditions in the reviewed studies.

The UK waste system in general

There is limited waste incineration in UK today compared with other countries, meaning that almost all waste material that is not recycled is currently landfilled. It further means that there is very limited recovery of heat at waste incineration – which could have relevance for material wastes that might be contaminated with organic matter (e.g. waste food containers) or combustible wastes. Note, however, that such organic contamination has typically not been dealt with by the reviewed LCAs. For any future plans to increase waste incineration capacity, the UK strategy on district heating and electricity generation will, of course, play a role for certain material waste streams. In this respect, other countries already have well established district heating infrastructure associated with 'energy from waste' schemes and these feature as system assumptions within the reviewed studies, in contrast to the current UK context.

Landfilling in the UK typically has gas collection and utilisation for electricity generation or heat and electricity co-generation. At some sites, this energy is used internally at the landfill only, at others, electricity is sold to the grid. The capture rate varies between 30-40% up to 70 %, and an average is judged to be around 50%. Any biogas formation from organic material that has been landfilled will, therefore, be captured and utilised to some extent. It must be noted, however, that methane is a 23 times stronger greenhouse gas than CO_2 (measured over 100 years), and any avoided CO_2 emissions due to substitution of other electricity on the grid will be superseded many times by the global warming contribution from the released methane.

Interpretation in the context of the UK energy and waste systems

The specific UK conditions for waste incineration and landfill do have a clear significance within the context of the reviewed LCAs. First of all, the comparisons made between recycling and landfilling were clearly relevant to the UK situation today. The results shown in Section 3 derived from scenarios with system boundary conditions not dissimilar to those found in the UK.

Secondly, UK conditions have implications for the interpretation of the issue of organic contamination of packaging materials, such as glass and plastics. As landfilling is currently the main alternative to recycling in the UK, high organic contamination of packaging materials should be seen in a different light, for instance, in the comparison between recycling and incineration in plastics study no. 9 (Frees, 2002). When a high level of organic contamination does not contribute to heat recovery, but on the contrary a high methane release from the landfill, recycling would most probably be favourable, even with a washing operation that uses hot water. This qualitative judgement is based on the knowledge of the proportions between the heat value of the organic matter, the global warming contribution from methane generated from the organic matter and the energy needed for washing. The judgement should, of course, be substantiated by a more thorough assessment.

Thirdly, the conditions of the UK energy systems, shown diagramatically in **Figure 4.1**, has implications for the interpretation of the frequency charts comparing recycling to incineration and for the judgement of any future plans for the expansion of waste incineration in UK. As the marginal electricity in UK derives from natural gas, there is no significant difference in conditions to the energy systems underlying results. A difference may prevail, if the UK expands waste incineration in the future but does not fully develop district heating and utilisation of the heat part of heat and power co-generation. Without the explotation of waste heat the incineration scenarios captured by the review would have had somewhat higher environmental impacts, implying recycling to be more favourable than the situation depicted in **Section 3**. Exactly how much the benefit would shift requires a deeper analysis. One implication of this is that recycling would come out more favourably in the comparison between recycling and incineration at lower substitution ratios, implying a better break-even for recycling in the case of plastics.

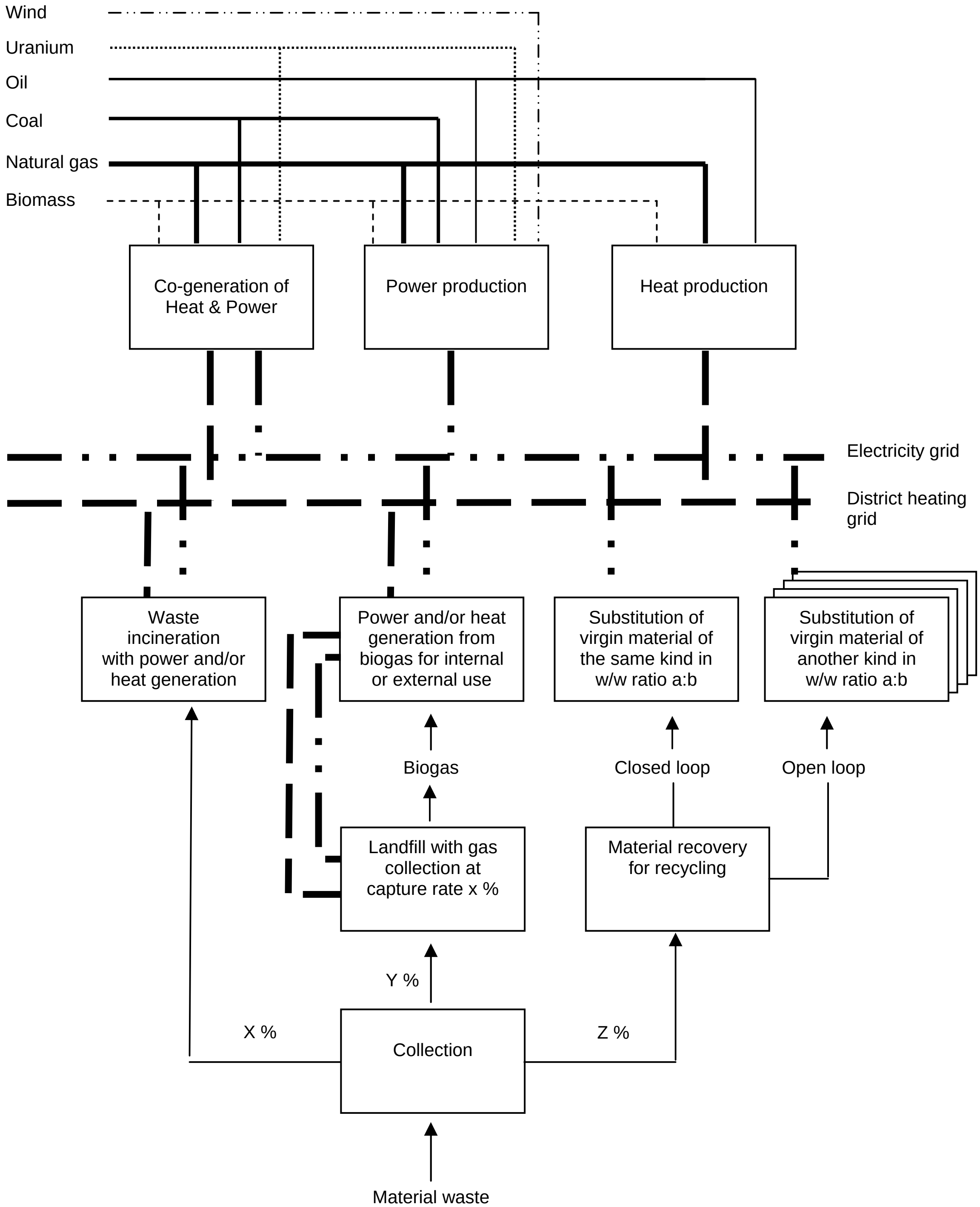


Figure 4.1. General outline of the interplay between the energy system and the waste management system.

Finally, for *open loop* recycling, which was discussed in relation to glass, care must be taken when extrapolating these results in a wider context. There is only one study of open loop recycling, so aspects of uncertainty call for caution. The environmental aspects of open loop recycling are highly dependant on the exact substitutions of other virgin materials and process improvements achieved by the recycling. Furthermore, as stated in the previous paragraph, a lack of utilisation of the heat part for district heating renders the UK condition a little less favourable to incineration than reflected by the assumptions in the scenarios of the reviewed studies. The main picture will, however, be broadly applicable as electricity substitution carries the main benefit.

The prevalent disposal route for waste in the UK is still landfill, and so open-loop recycling should be compared to this to reflect current conditions. More research is required in this area to provide complete reviews of a range of open loop scenarios.

The following sections discuss for each material the factors that influence interpretation of the review results in the UK context.

4.3.2 Paper and cardboard waste management system

As the markets for paper and paper scrap are almost fully global, and as collection and any pre-processing operations prior to market access are insignificant, the specific UK conditions in the paper waste management system are judged to be insignificant.

4.3.3 Glass waste management system

Glass being recycled in UK is used for a number of applications both in the UK and abroad. A distinction has been made between two kinds of recycling, closed loop and open loop recycling. By the closed loop recycling, cullet substituted raw materials, mainly sand, in the production of glass products, e.g. bottles and other containers in glass. The environmental implications of this are two-fold, both an avoidance of the raw material extraction and an improved process performance (reduced energy consumption) of the glass making. In open loop recycling, cullet is used as a raw material for products other than conventional glass products, such as fibre glass, filter media or aggregates (e.g. for soil drainage).

The environmental implications of open loop recycling vary according to which material substitutions and process alterations are induced/achieved by the use of cullet.

Examples of achieved benefits of open loop recycling are:

- Fibre glass: avoided raw material (sand) extraction and reduced energy consumption in fibre glass production
- Filter media: avoided production of other filter media and reduced energy consumption (due to reduced friction) of the filtering operation
- Aggregates for soil drainage material: avoided extraction/production of other drainage material, e.g. small stones.

Due to the dependence of the specific open loop application of the cullet, care must be taken in interpreting the reviewed open loop scenarios as representative for open loop recycling in the UK. Presumably, the reviewed scenarios for fibre glass production are quite representative for UK conditions, but other applications may not be. The scenario for using cullet for filter media production, for example, does not seem to include any benefits in terms of reduced energy for filtering, which may be achieved by filter media made from cullet. It is clearly important that the implications for water pumping efficiencies and any associated energy savings should be included in such assessments.

The reviewed open loop scenarios indicated that recycling is environmentally preferable if both raw material (e.g. sand or aggregates) extraction is avoided and some kind of process improvement is achieved by using cullet, whereas landfilling is more favourable if the cullet only replaced the raw material (sand or aggregates). But the statistical basis of this interpretation is much too limited, and a specific study on UK open loop recycling would be needed for any general interpretation of this type of recycling.

4.3.4 Plastics waste management system

Recycled plastic and process plastic scrap (from manufacturing of plastic products) is used for a number of applications in the UK. As with glass, a distinction can be made between closed loop and open loop recycling.

By the closed loop recycling, recycled plastic material substitute virgin plastic material, and a key environmental issue is, as previously seen, at which ratio the substitution takes place. By open loop recycling, products made form recycled plastic material substitute products that would otherwise have been made from other materials like wood or aggregates.

In the UK, plastic waste material in the form of plastic film from industrial packaging (around 300,000 tonnes/year (2004)) and bottles from households (around 35,000 tonnes/year (2004)) is being recycled. More than 50 % of this is exported, the Chinese market being the main consumer.

Regarding closed loop recycling, the products manufactured from recycled plastic material in the UK include refuse sacks, components for cars, kerbside boxes and drainage pipes. In all cases, the substitution ratio is believed to be 1:1. The UK plastic waste management system, thus, is in line with the majority of scenarios in the reviewed LCAs anticipating a virgin material substitution in a 1:1 ratio. The conditions of the UK plastic waste management system, therefore, do not imply any further modification of the review findings.

Regarding open loop recycling, products manufactured from recycled plastics comprise fences, outdoor furniture, playground equipment, paving and many more. The most commonly used recycled materials are HDPE, LDPE, PP and PS, and the substituted virgin material would be wood or aggregates. The review did not contain any studies looking at open loop recycling of plastics, and there is, thus, no interpretation possible on this. A new analysis would be required to fill this gap.

4.3.5 Aluminium and steel waste management systems

Virgin aluminium and steel are both traded in global markets and so is recovered metal scrap. Specific conditions for UK virgin metal production and remelting are, therefore, not that relevant as these operations presumably will not respond significantly to any increased metal waste collection, but only to prices on the material exchange. In any case, the technologies for steel and aluminium manufacture is not believed to be significantly different in UK compared with elsewhere.

As any changes in steel/aluminium recycling in the UK will influence the specific incineration and/or landfilling systems in UK, and as waste incineration and landfilling do not interplay with any markets outside UK, these specific systems will, of course, be influenced.

Consequentially, only recycling operations prior to market access are specifically UK related, i.e. collection, transport and any pre-processing. And these have minor significance. End disposal at landfills and waste incinerators, however, are fully UK specific.

4.3.6 Wood waste management system

The total amount of post consumer wood waste in the UK amounts to 5-7 million tonnes/year. In 2004, a total of 1.22 Mtonnes of wood waste of high quality was recycled, which mainly consisted of pallets and other packaging waste. The majority of this fraction was used for the manufacturing of fibreboard containing typically 60 % recycled fibres. The rest of the high quality fraction was used for added value products like animal bedding, weed control etc.

The medium quality fraction originates from consumers and industry including furniture and other items. This fraction is not recycled to any significant extent, and neither is the low quality fraction originating mainly from construction and demolition. This fraction also holds hazardous waste – e.g. from pressure-creosoted wood arising from building demolition.

The reviewed studies contained no scenarios for wood recycling, neither closed loop nor open loop. No comparison could therefore be made between wood recycling versus incineration or landfill. Scenarios for closed loop recycling would require collection of information on virgin wood substitution, whereas scenarios for open loop recycling would require information on the variety of other materials, substances and processes being replaced by recycled wood, e.g. aggregates, straw/hay or herbicides (when wood chips are used for weed control).

4.3.7 Aggregates waste management system

The selected studies represented Italian (AG-1) and UK-based (AG-2) research, respectively. Two issues seem prominent with respect to the transferability of this review's results into a UK context:

1. Transport issues
2. Material replacement issues including related energy marginals

A comparison of a system in which landfilling would be the only disposal option for construction and demolition waste with a full aggregates recycling system is in essence a comparison of 1) on the one hand, primary aggregate extraction and production plus transport to the construction site plus transport and landfilling of construction and demolition waste, with 2) on the other hand, recycled aggregates production plus waste sorting/processing and transport.

Waste sorting and recovery processes can - in environmental terms - be considered almost identical to crushing and screening processes. Also, UK-border-crossing exchanges (especially export) through international trade are considered irrelevant due to the relatively low value per tonne aggregate and resulting low incentive for international trade. Therefore, the relevant processes for comparison are considered to be extraction and transport to construction site on the one hand and transport related to recycling on the other.

One characteristic of the situation in the UK is a relatively low number of supply locations for primary aggregates and a relatively high number of landfill sites. Transport from primary UK aggregate production sites to construction sites is typically interregional, e.g. for the volume-wise dominating 'crushed rock' mostly from South West England and the East Midlands to the East of England and the South East, with correspondingly long transport distances.

The currently long transport distances can be expected to be shortened substantially by means of wide-spread installation and increased utilisation of recycling facilities and would be shortened even more substantially by increased on-site recycling. However, the exact number and locations of suitable off-site recycling facilities could not be determined within the present review.

The material that would be replaced by an increased amount of recycled aggregate is mostly primary aggregate and the energy marginal involved to run the increased recycling processes is natural gas.

Due to the relevance of the issues of transport and material replacement, both related to recycling benefits, these issues may be further investigated in the course of a dedicated study focusing on existing knowledge gaps.

5. Conclusions

5.1 Paper and cardboard

This review of existing studies comparing the environmental aspects of the waste management of paper and cardboard demonstrates that recycling was by practically all existing studies found to be environmentally preferable to landfilling and to the prevailing mix of incineration and landfilling in the studies and countries covered by the studies, which was around 20-30% incineration and 70-80% landfilling.

Only one scenario comparing incineration to landfilling was identified, and it showed a clear preference for incineration.

The immediate picture of the comparison between recycling and incineration was more complex. Within some impact categories, recycling was found by the majority of studies to lead to reduced impacts. This was the case for:

- overall energy consumption,
- energy related impacts of acidification, nutrient enrichment and photochemical ozone formation,
- toxicity, and
- other impacts (COD in wastewater effluents and land use)

Within other impact categories, the results of the reviewed studies showed more evenly distributed advantages and disadvantages between recycling and incineration, i.e. the categories of:

- consumption of fossil fuels,
- global warming, and
- solid waste

for which global warming and fossil fuel consumption are strictly correlated.

Results on overall energy consumption followed a very evenly distributed normal distribution, with an average of 50% less energy consumption when recycling instead of incinerating paper and cardboard. In other words, on average virgin production followed by incineration with energy recovery consumed twice as much energy as recycling. The reason that this result did not reproduce itself for the energy related impacts was that the energy systems behind virgin paper/cardboard production and paper/cardboard recovery are quite different: whereas the energy underlying virgin production is to some extent based on CO_2-neutral fuels, the paper/cardboard recovery operations are typically solely based on fossil fuels.

The reason that compilation of results on global warming and fossil fuel consumption showed a large variation and an unclear preference was explained by the way in which these studies handled differences in the underlying energy systems in their system boundary settings within their various scenarios. This variation is to be expected, as the many of the scenarios in certain studies were set up specifically to examine the dependency of results and conclusions on variations in key assumptions.

A closer analysis showed that results and conclusions on global warming and fossil fuel consumption were conditional to four key issues:

1. The energy split between electricity and thermal energy in production of the various virgin paper and cardboard types.

2. The marginal electricity assumed for virgin paper/cardboard production

3. The potential utilisation of the extra incineration capacity created by recycling to reduce landfilling

4. The inclusion of an opportunity cost of using wood for virgin paper/cardboard production

The cause-effect relationships between assumptions on these issues and results/conclusions on global warming have been fully analysed. They show that for newsprint, for which the energy for virgin paper production is mainly electricity, recycling was clearly preferable. Only a few scenarios, which, probably incorrectly, assumed that the marginal electricity on the grid was based partly or fully on wood, found incineration to be preferable. With the proper use of marginal electricity there seems to be little doubt that recycling is preferable for newsprint on global warming and other impact categories – as well as any other paper and cardboard category being made from thermo-mechanical pulp, TMP or chemical-thermo-mechanical pulp, CTMP.

For paper and cardboard categories on the other hand, for which the underlying energy system of virgin production was mainly thermal energy being produced from wood, like for craft pulp, the conclusion on global warming remained conditional on a few key assumptions for which no clear right or wrong could be identified without a closer analysis. It has been established that recycling produced huge CO_2-eq. savings, if either of the two following assumptions was made:

- the extra capacity of waste incinerators being released as a result of recycling can be utilised to reduce landfilling of burnable wastes or
- that society is facing a future in which there will be an opportunity cost associated with using wood in the sense that would deprive society of the opportunity of using it in the energy sector.

Conversely, it has been found that incineration instead of recycling will lead to CO_2-eq. savings, if it was assumed that the above mentioned conditions were not fulfilled.

These conclusions were derived from 9 studies comprising a total of 63 scenarios comparing the three waste management options to each other. The studies were selected based on a literature search in the original study underlying this report (Villanueva *et al.,* 2004) which screened several hundred studies. A first sift identified 9 studies on the LCA methodology for environmental assessment of paper and cardboard, 42 Life Cycle oriented case studies, 20 Life Cycle oriented studies on waste and 37 non-LCAs (e.g. cost/benefit analysis, CBAs) as potential candidates for the review, and these studies were then evaluated individually leading to the final selection of the 9 studies for in-depth review.

A very wide variety of paper and cardboard types were covered by the reviewed studies: newsprint, newspapers, magazines, mixed paper, office paper, writing paper, graphic paper, corrugated cardboard, paper board, CUK paper board, and SBS paperboard. Moreover, the studies covered many different geographical regions worldwide. In general, therefore, the conclusions of this review were believed to be robust.

To further improve the knowledge of the environmental aspects of end-of-life management for paper and cardboard, the priority would be to study more closely the identified system boundary assumptions that were decisive to conclusions on global warming and fossil fuel consumption. On these issues, however, stakeholders in the environmental aspects of waste management of paper and cardboard would benefit much from a deeper analysis of the future developments and probabilities of which system boundaries will in fact exist, across a number of key questions:

- What are the incineration and landfill capacities in the country/region in question? What is the short and long term match of these capacities with the waste flows, and what is the waste management policy? Will a release of incineration capacity due to more recycling be used to take in more burnable waste from landfills? What are the short term and long term aspects of this?

- Does society face a future in which wood and other biomass becomes a priority fuel in the energy sector, perhaps as a component of CO_2 reduction policies, fuel scarcity or economic relations in general? Will there be an opportunity cost associated using wood?

It is possible to do a meaningful analysis of these issues, and this has been identified as the highest priority to further qualify future statements on the environmental aspects of waste management for paper and cardboard.

5.2 Glass

Whereas it was a robust conclusion that closed loop recycling of glass was preferable to both incineration and landfilling in environmental terms, a broad generalisation was not possible for open loop recycling. All scenarios included in the LCA studies analysed concluded that closed loop recycling of glass had a lower environmental impact than the alternatives of incineration or landfilling. This also applied to open loop recycling into glass fibre insulation, clay bricks and shot blast abrasive. However, some types of open loop recycling, such as in aggregates or filtration media, were found to be disadvantageous. It should be noted that this conclusion was based on only one study, considering open loop recycling as compared with 11 studies that considered closed loop recycling.

The overall conclusion from the present review was based on the results from 11 studies fulfilling the selection criteria in a comprehensive literature search. A crucial selection criterion has been that the study should include a comparison of end-of-life waste management, and no studies including an end-of-life comparison have been excluded. In total this review comprised 25 different scenarios, carried out in different geographical regions, and including different assumptions.

Most of the impact categories contained in the reviewed glass studies were related to energy consumption. This explains why the environmental benefits of recycling have a similar relative magnitude expressed in percentages in most of the impact categories reported in the studies.

One of the consequences of this is that the most important assumptions for the results of the studies were those associated with energy, especially the electricity marginals for virgin and recovered materials.

The majority of studies used average energy mix scenarios taken from databases in Western European countries, USA and Australia. These were subsequently energy mixes mainly based on fossil and nuclear fuels. However, several studies did not provide information on the energy sources and energy substitution used in their calculations.

The closed loop recycling scenario 6.3 by RDC & Coopers and Lybrand (1997) was the scenario most significantly deviating from the remainder of closed loop recycling scenarios. As mentioned earlier, this scenario was a mathematical exercise that compared a pessimistic recycling situation with an optimistic incineration situation, neither of which was typical of ‘real life’. The scenario presupposed a poor recycling rate, collection from low-density housing and long transport distances for recycling compared with incineration.

Some scenarios from Enviros (2003) seemed to reach conclusions differing from the vast majority of studies, and it is noted that these scenarios covered open loop recycling processes. Hence, the scenarios 2-4 and 2-5 showed examples of glass ‘down-cycling’ where the energy need in the collection and recycling process exceeded the energy used for the manufacture of the raw materials. These scenarios cannot be characterised as being regular outliers, even though their conclusions were different from others, but rather as scenarios belonging to a different data population, namely specific categories of open loop recycling.

The results and interpretation of closed loop recycling have general validity, and they represent UK conditions well. The comparison of recycling versus landfilling was the most relevant to current UK waste management. But the comparison between recycling and incineration also reflects any future choices between recycling and incineration in UK well.

The review did not allow for a general interpretation of the environmental implications of open loop recycling, nor any interpretation of specific UK open loop recycling.

Seven out of eleven of the studies analysed were multi-material packaging studies. The remaining studies partly also covered packaging. No specific product categories other than packaging were included in the studies reviewed (e.g. flat glass).

The review did not allow for an interpretation of waste management of glass waste that contained high levels of organic contamination.

5.3 Plastics

This review comprised 10 studies, including a total of 60 scenarios comparing the three plastic waste management options of recycling, incineration and landfilling to each other. The studies covered many different geographical regions from Norway, Sweden and Denmark in the North to New Zealand in the South and comprising both the EU and the USA.

The literature search identified initially over 200 studies and a first screening selection identified 42 studies as potential candidates for the review, and these studies were then evaluated individually, leading to the final selection of the 10 studies for review. As it turned out, all studies including quantitative LCA- or LCA-like comparisons of plastic waste management options also complied with other quality criteria and were included in the review. Due to time and budget constraints, a few (2-3) of the identified 42 studies were not evaluated, and an evaluation of these might conclude that they in fact met the quality criteria for inclusion in the review. But beside these potential further candidates, the review is believed to have identified more or less all relevant studies available in the literature. The conclusions of this review are, thus, believed to be robust.

Three main issues were identified that divided the plastics scenarios into distinct groups:

I. Scenarios that anticipated recovered material to substitute virgin material of the same kind in the weight/weight ratio of 1:1
II. Scenarios that anticipated recovered material to substitute virgin material of the same kind in the weight/weight ratio of 1:0.5
III. Scenarios that included substantial washing/cleaning of the plastic product before material recovery was possible, in which this washing/cleaning was found to be of great environmental significance

The vast majority of scenarios belonged to group I. With this basic assumption for material recovery, all reviewed studies and scenarios concluded recycling/material recovery to be environmentally better than both incineration and landfilling on all environmental impact categories included in the studies, with recycling being around 50 % better on average. The net CO_2 saving from recycling was found to be 1.5 – 2 tonnes CO_2-eq. per tonne of plastics on average. In a UK context, in which only electricity and not heat from waste incineration is utilised, the comparison between recycling and incineration would be slightly more favourable to recycling.

In cases where the substitution ratio was worse that 1:1, the scenarios dealing with this issue showed that a ratio of 1:0.5 was about the break-even at which recycling and incineration were environmentally equal. In a UK context, in which only electricity and not heat from waste incineration is utilised, the break-even would be slightly better for recycling.

In cases with substantial washing/cleaning of plastics with high COD contamination (e.g. 1 kg COD/kg plastics), the scenarios dealing with this demonstrated that this may lead to incineration being environmentally preferable to recycling. This was as a result of using hot water for washing processes and the fact that the organic contaminants had a heat value that was advantageous in the incineration scenarios, but disadvantageous to recycling processes, because the removal of contaminants in municipal wastewater treatment required energy. In a UK context, in which landfilling and not incineration is the main alternative to recycling, the generation of methane from landfills would probably reverse the picture and show environmental advantage of recycling also for plastics highly contaminated with COD. A deeper analysis would be required to justify and quantify this statement.

The studied waste streams comprised the thermoplastics PVC, PP, LDPE, HDPE, and PET. Studies on other plastics like PS, EPS, PA, PC, ABS/SAN, and PUR were not identified, and such studies have, probably, not been performed due to a lack of interested stakeholders so far. The plastics comprised by the identified studies were present in municipal solid waste in general and in products like packaging (the most frequent product category represented), farm waste (field cover, silage films and chemical containers), cables and car bumpers. As the main benefit of recycling versus incineration lies in the saving of processing energy for oil refining and polymerisation of monomers, and as this benefit does not differ significantly from polymer to polymer, the type of polymer was not highly significant to the outcome.

The scope of interpretation was, thus, relatively clear with respect to closed loop plastics recycling. Firstly, there was little doubt that closed loop recycling was environmentally preferable to incineration, if the recovered material in practice could substitute virgin material by a weight ratio of close to 1:1 or better than 1:0.5. The question was, however, to what extent this could be realised in practice? This is where the next generation of analyses of closed loop recycling should be focused: for which applications of plastics – in which product categories – can plastics beneficially be recovered, and which product categories can receive the recovered plastics? The next generation of analyses comparing closed loop recycling to incineration with energy recovery is, thus, an issue of logistics and technical understanding of the quality issues of the various types of plastics. This point is well acknowledged by most professionals dealing with recovery of plastics, but nevertheless, it should be emphasized that this is where the need for knowledge lies.

Also, the present review did not investigate the significance of separation technologies for more complex products, because mainly mono-material products have been studied. Systems requiring dismantling, sorting, shredding and the environmental feasibility of plastics recycling in cases where such sorting/separation measures are required, were not represented in the existing studies.

With respect to open loop recycling, there did not seem to be any knowledge available in literature, which is a significant and unfortunate knowledge gap.

5.4 Aluminium

With the exception of a single outlier (AL-4.3), all scenarios described in the analysed LCA studies concluded that recycling of aluminium had a lower environmental impact than the alternatives of incineration or landfilling.

This overall conclusion from the present review was based on the results of 11 high quality studies, comprising 20 different scenarios, carried out in different geographical areas and including different assumptions.

Regarding the assumptions made in the reviewed LCAs, the most important were those associated with the electricity marginal for virgin and recovered material. Four studies considered this aspect but chose not to include it in their study. The other seven studies were based on average energy scenarios from Western European countries, USA and Australia. These were thus mainly based on fossil and nuclear fuels.

The assumptions underlying the outlier scenario AL-4.3 were based on a scenario of a pessimistic recycling compared with a scenario of optimistic incineration. The latter assumed that only 20 % of the aluminium would be oxidized during the incineration process and furthermore that it would be possible to extract 80 % of the aluminium from the slag.

The sensitivity towards this post-incineration recycling rate was accentuated by calculations showing that recycling became clearly the preferred option compared with incineration if the post-incineration recycling rate fell below 65-70%. The authors concluded that this was probably very often the case in the EU. This scenario, which was characterized as an incineration scenario in this report, was thus merely a 'post-incineration recycling' scenario. One could thus argue that scenario 4.3 was, in fact, a comparison between two different recycling scenarios.

Most scenarios included in the LCA studies concluded that recycling of aluminium had a lower environmental impact than the alternatives of incineration or landfill. The environmental benefits of recycling were demonstrated almost equally across the 7 different impact categories extracted from the studies.

The overall conclusion from the present review was that the results from the 11 studies comprising 20 different scenarios, produced in different geographical areas, and including the different key assumptions mentioned, indicated that recycling had a better environmental profile than incineration or landfill.

The studied waste stream types comprised either 'packaging' or 'waste' in general, no specific product categories other than packaging were identified. On the one hand, this limits the interpretation to this specific aluminium product type, on the other hand, there was no doubt that the conclusions, at least qualitatively, were robust and thus also applicable to aluminium-containing products in general: recycling seems environmentally advantageous compared to both incineration and landfill. There may be quantitative differences due to differences in impacts from product-dependent handling, but the conclusion remains robust. There is one over-riding reason for this, namely that production of virgin aluminium requires around 10-20 times more energy than aluminium recovery.

5.5 Steel

With the exception of a single outlier, all scenarios included in the LCA studies analysed concluded that recycling of steel had a lower environmental impact than the alternatives of incineration or landfilling.

The overall conclusion from the present review was based on the results from 9 studies comprising 20 different scenarios, carried out in different geographical areas, and including different assumptions.

Most of the impact categories contained in the reviewed studies were related to energy consumption. This is one of the possible explanations of why the environmental benefits of recycling had a very similar relative magnitude expressed in percentages in most of the impact categories reported in the studies.

One of the consequences of this was that the most important assumptions for the results of the studies were those associated with energy: the electricity marginals for virgin and recovered materials, and the energy substituted by incineration.

However important, four of the studies (ST-9, ST-8, ST-7, ST-6) did not provide at all the information on the energy sources and energy substitution used in their calculations. From the five remaining studies, three of them used average energy mix scenarios taken from databases in Western European countries, USA and Australia. These were thus energy mixes mainly based on fossil and nuclear fuels.

As energy was so dominant in the results presented in the studies reviewed, it is therefore important to stress that none of the studies used energy marginal values instead of averages. A study collecting and analysing in detail the sensitivity to the energy supply origin would be valuable to shed light on this issue.

There was a clear outlier in the comparison of recycling and incineration, scenario ST-8.3 from RDC & Coopers and Lybrand (1997). As with the aluminium outlier already discussed, this scenario was a theoretical mathematical exercise based on a pessimistic recycling situation compared with an optimistic incineration situation. This optimistic incineration scenario assumed that it was possible to extract 90 % of the steel from the slag, which in plain words means that it was in fact another 'post incineration recycling' scenario. The sensitivity towards this post-incineration recycling rate was analysed in the study, with calculations showing that recycling became clearly the preferred option compared with incineration if the post-incineration recycling rate was below 50%. The authors of the study concluded that this was probably very often the case in the EU.

Seven out of nine of the studies analysed were multi-material packaging studies. The other two did not specify any product. Thus, no specific product categories other than packaging were included in the studies reviewed.

Packaging studies match the right scope and goal of this review, and are therefore the studies best fitting this review's scope and selection criteria. However, the description of the material in such studies is in general of lower quality than steel-specific LCAs, and rely more on data from databases than directly from specific steelworks. This is partly explained because packaging studies frequently cover a wide span of materials, and often not only focus on LCA but also on economic or socio-economic evaluations, and thus lack the necessary insight into the particularities of the steel system. The analysed packaging LCA studies frequently do not solve clearly material quality and substitution questions, nor do they clearly explain the incineration energy allocation methods used.

Despite these drawbacks, there is no doubt that conclusions, at least qualitatively, were robust and thus also applicable to steel-containing products in general: recycling is environmentally better than both incineration and landfill. There may be quantitative differences due to differences in the products that are made of steel (a car, a beam, a stainless steel turbine) and impacts from product-dependent handling (pre-consumer recycling, post-consumer recycling), but the conclusion remains robust. Moreover, the results and interpretation represent UK conditions well.

Part of the explanation for this robustness is the fact, that production of virgin steel, taking almost 75% of the energy of the steel's lifecycle, requires around twice as much energy than the production of steel from scrap.

Note, however, that the environmental aspects of steel waste with a high organic contamination (e.g. food packaging) cannot be interpreted from the results of this review as this isue was not tackled by any of the studies.

5.6 Wood

The review of existing wood waste studies comparing the environmental aspects of waste management confirm the prevailing understanding that incineration with energy recovery is environmentally better than landfilling. In quantifying the relative improvement from incinerating wood instead of depositing it in landfills, it was found that the improvement was well over 100% on average, the high figure deriving from the fact that wood incineration substitutes fossil fuels in the energy sector. The saving of CO_2-eq. emissions from wood incineration instead of landfilling was around 1.5 tonnes CO_2-eq. per tonne of wood on average. As one of the three reviewed studies did not account for methane emissions from wood at landfills, this figure is in reality probably somewhat higher, and some of the scenarios in the other studies including methane emission report savings up to 3.0 tonnes CO_2-eq. per tonne of wood.

This conclusion derives from only three studies that met the selection criteria, comprising a total of 7 scenarios comparing wood incineration to wood landfilling. The literature search had produced several hundred titles, which were narrowed down to 29 studies as candidated for more detailed review. No studies were identified that included wood recycling. The studies related to Germany, Austria, Canada and the Nordic countries, but represent a comparison of wood waste incineration versus landfilling that would be relevant to the UK context quite well.

The conclusion, that it is environmentally better to use waste wood for energy purposes substituting fossils fuels than to deposit the wood on landfills, is not surprising. It was unfortunate that none of the investigated studies considered the recycling of wood, because a comparison between recycling and incineration of wood does not have the same intuitively obvious answer. Consequently, whilst we can conclude that the recovery of energy from wood waste is generally better than disposal to landfill, we cannot conclude whether recycling is better or worse than either landfill or energy recovery.

Only energy consumption and energy related environmental impacts were considered by the reviewed studies. Other impacts, including influence on biodiversity from forestry, would not, however, tend to change the conclusions of comparisons between incineration and landfilling, as these waste management options tend to have the same consumption of wood and thus the same volume of forestry. If, however, recycling scenarios had been included, the draw on timber would have been different from such scenarios as a result of wood being recovered.

The studied waste stream types comprised laminated wood and wood from demolition. This does not limits the interpretation much, but in case of significant product dependant wood recovery prior to the waste management, there may be significant differences for other product categories. The present review did not investigated the significance of separation technologies for more complex products.

The scenarios comparing wood incineration can be interpreted directly in a UK context with respect to energy recovery in UK energy plant. For UK waste incineration, however, any lack of utilisation of the heat part in district heating makes incineration a little less favourable than reflected by the studies, but still environmentally superior to landfilling.

5.7 Aggregates

All scenarios described in the two analysed LCAs concluded that recycling of aggregates had a lower environmental impact than the alternative of landfilling. While most scenarios resulted in moderate savings, one scenario (1.1) reported significantly lower relative impacts from recycling.

This overall conclusion was based on the results of 2 studies that met the selection criteria drawn from a longer list of 24 reviewed studies. The 2 studies contained 6 different scenarios, carried out in different geographical areas and including different assumptions.

The incineration of aggregates was not treated as realistic waste management option in any of the 24 reviewed studies.

Regarding the assumptions made in the reviewed LCAs, the most important were those associated with the substitution of virgin material and the product-dependant recovery processes. Both studies considered this aspect, but arrived at varying degrees of relative reductions in potential environmental impact.

Transport processes, involving fossil fuel consumption, were especially influencial in the recycling scenarios, as these required additional transport activity, depending on whether or not the processing was performed on-site or off-site. Three scenarios that required significant extra transportation (1.1, 1.2 and 2.1) reported higher impacts for ’other road transport’ effects from recycling relative to landfilling.

The assumptions underlying the outlier scenario 1.1, which reported extremely high reduction potentials through aggregates recycling, were based on high stated values quoted for virgin material production compared with other studies.

The scope of interpretation was considered relatively narrow as almost all evaluated studies - including the rejected ones – indicated that recycling was environmentally preferable. There may be quantitative differences due to differences in impacts from product-dependent handling, but the conclusion remains robust. The main reason for this is the fact that production of virgin aggregates requires substantially more energy than aggregates recovery.

Probably due to the significant quantities arising, most reviewed studies and especially the two in-depth analysed studies, dealt with aggregate wastes from construction and demolition sites and not in the form of, for example , asphalt or concrete waste from road construction. Results, however, are considered to be valid for all types of aggregate wastes, except with regard to the recycling processes involved.

As product-dependant recovery processes were found to be important for the overall result, future studies might investigate this issue for the different types of aggregate wastes and for different aggregate-based products, e.g. more complex/multi-material or more simple/mono-material products, more steel-based constructions vs. concrete-, brick- or asphalt-based constructions, etc.

Differences may be important in an overall perspective, as amounts, treatment processes and accessibility of waste products may differ widely within the different product types.

Overall, the comprehensive, global search process within this study has revealed a lack of detailed, quantitative, comparative studies on waste management options for aggregates. This is manifested by the fact that only two out of 24 studies (and actually many additionally noticed ones) included such a comparison. Considering the immense societal impact of aggregates in construction, buildings and other structures in the built environment, further comparative LCAs would be of great benefit.

Appendix 1. Literature review methodology

This appendix describes the approach, procedure and results of the search process that formed the basis of the review. The plan is valid for all materials with the exception of paper and cardboard, which is described separately below. The description covers the search plan followed, the chosen search criteria, the search response and the list of studies selected at the end of this stage.

Overall search plan

The aim of the search plan was to tap all accessible sources of information about potentially relevant LCA studies. In order to accomplish this aim, a three-pronged approach was chosen:

1. A targeted search by personal contacts to a large number of LCA institutions and experts, and institutions worldwide
2. A broad search of libraries and scientific literature databases
3. A broad Internet search via search engines and homepages of high-potential institutions (mainly national Environmental Protection Agencies) around the world

The targeted search

Based on experience from similar review studies and literature searches in the review study on paper and cardboard (Villanueva et *al.,* 2004) and the review on PVC (Baitz *et al.*, 2004) it was anticipated that a targeted search based on the project team's contacts to international LCA institutions and LCA experts, as well as to national and international institutions and organisations would be a source of highly qualified studies.

Most experts were identified through the network of the project team, while most institutions and organisations were either known from previous studies dealing with the particular materials or identified through a general Internet search.

The targeted search led to the list of institutions and organisations included in **Appendix 2**.

The targeted search for waste and LCA experts delivered also many multi-material references, especially packaging studies including glass, plastic, wood, aluminium and steel. Due to this synergy effect, a fully traceable response rate is not possible to identify on these studies. However, in qualitative terms the response rate from LCA institutions and experts is considered satisfactory in terms of number of responses and in fact very good regarding the quality of the references and documents obtained in this way.

Overall, the targeted search is considered very successful for identifying LCA studies on each material. The project team is confident to have covered the majority of existing studies covering all stages of the material lifecycle and, equally importantly, including the disposal phase.

The broad search of libraries and scientific literature databases

The main source in this second string of our search approach was the search database DADS of the Technical University of Denmark (http://www.dtv.dtu.dk/English.aspx). DADS covers international journals, books, conference proceedings, dissertations and reports and contains citations of about 29 million articles, approx. 5 million of which are in full text.

This string of the search was very comprehensive and led to many references that were not detected in other ways (e.g. papers in non "typical" LCA journals, e.g. energy journals or material-related manufacturing journals). Therefore also this part of the search approach is considered successful.

The broad internet search

The third string in our search approach, a broad internet search, was performed using search engines, such as Google, Google Scholar and Altavista. In parallel, homepages of environmental institutions were searched in this step, especially EPAs in North America, Australia and Europe. In addition, the webpage of the European Commission was searched for studies commissioned as input to EU policies. EPAs were searched specifically because many of their publications are not accessible via Internet search machines. At the same time, it is the experience of the project team that national EPAs are potential commissioners of large LCA studies.

Source languages covered are English, German (including Swiss and Austrian), Spanish, French, Portuguese, and Nordic languages (Danish, Swedish, Norwegian).

Search coverage

As a joint result from the three-string search approach, a short list of LCA studies and papers were chosen for evaluation.

The short list, supplied in **Appendix 3**, is characterised by:

- packaging studies, comprising several materials
- papers from international journals, some of them condensed versions of full-size reports, others with no additional background information.
- database or life-cycle inventory studies of a material or of several materials, but not providing any assessment

Paper and Cardboard Literature basis

The starting point for the elaboration of the review 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 90’s, and most of them in Europe. The publication of such studies has continued in the late 90’s and after 2000, but the methodology used in them seems to have switched slightly from being purely environmental studies (LCA included) in the mid-90s towards combined environmental-economic studies in the late 90s 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 social perspective are elaborated for assisting policy-makers in the selection of the best strategies for the management of used paper and cardboard.
- 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 can be to support internal environmental improvements, including reduction of emissions, optimisation of energy use, adoption of best available technologies, environmental management system compliance, etc. or it can be more strategic to sustain the business and marketing of the company.

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.

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 was contacted and requested to contribute with relevant references.

Appendix 2. European institutions contacted

Paper LCA contacts

Belgium	• VITO, Belgium
Denmark	• IPU-Institute for Product Development , Denmark • COWI Consulting, Denmark • dk-Teknik Energy & Environment, Denmark • IPL - The Department of Manufacturing Engineering and Management, Technical University of Denmark, Denmark • LCA 2.-0 Consultants, Denmark • Niras, Denmark
Finland	• Finnish Environment Institute, Finland • Finnish Forest Industries Federation, Finland • Jaakko Pöyry Oyj, Finland • KCL, Finnish Pulp and Paper Research Institute, Finland • University of Helsinki, Finland • VTT Industrial Systems, Finland
France	• CARAT Environment, France • Ecobilan, France • Eco-conception conseils, France • O2 France, France
Germany	• TU Dresden- Institut für Abfallwirtschaft und Altlasten, Germany • C.A.U. GmbH, Germany • Five Winds International, Germany • GesPaRec, Germany • IFEU-Institut für Energie- und Umweltforschung, Germany • IÖW, Germany • ISO-Institut Köln, Germany • LCE Consulting GmbH, Germany • Ökoinstitut, Germany • PE Engineering, Germany
Greece	• Aristotle University, Thessaloniki Laboratory of Heat Transfer and Environmental Engineering, Greece

Italy

- Ecobilancio, Italy
- Febe EcoLogic, Italy
- Life Cycle Engineering (LCE), Italy
- Seconda Università degli Studi di Napoli, Italy

Netherlands

- CE Delft, The Netherlands
- IVAM, The Netherlands
- PRé Consultants, The Netherlands
- TNO Bouw, The Netherlands

Norway

- Elopak, Norway
- STØ- Østfold Research Foundation, Norway

Portugal

- INETI-The National Institute of Industrial Engineering and Technology, Portugal

Spain

- Randa Group, Spain

Sweden

- CIT Ekologik AB; Chalmers Industriteknik, Sweden
- CEPI Eurokraft, European Kraft Paper Producers for the Flexible Packaging Industry, Sweden
- Chalmers University of Technology, Environmental Systems Analysis, Sweden
- Chalmers University of Technology, Physical Resource Theory, Sweden
- Framkom – The Swedish Research Institute for Media Technology, Sweden
- Högskolan Dalarna, Sweden
- IVL -Swedish Environmental Research Institute, Sweden
- Karlstad University, Department of Environmental and Energy Systems, Sweden
- Skogforsk – the Forestry Research Institute of Sweden, Sweden
- Packforsk - The Swedish Institute for Packaging and Logistics, Sweden
- STFI - The Swedish Pulp and Paper Research Institute, Sweden
- Stora Enso, Sweden
- Trätek – The Swedish Institute for Wood Technology Research, Sweden

Switzerland	• Doka Oekobilanzen, Switzerland • EcoIntegra, Switzerland • ESU services, Switzerland • Sustainable Asset Management, Switzerland
United Kingdom	• Boustead consulting, U.K • CSERGE - Centre for Social and Economic Research on the Global Environment at the University of East Anglia, U.K • EuGeos Limited, U.K • University of Surrey, Centre for Environmental Strategy, U.K • PIRA International, U.K

Glass LCA contacts

No.	Organisation	Continent	Address	Outcome
1	FEVE **-** European Container Glass Federation http://www.feve.org/	Europe	Avenue Louise 89, Bte 4 B-1050 Brussels Belgium info@feve.org Mr Guy Robys	Refers to German and Swiss studies on packaging
2	The Glass Packaging Institute (GPI) http://www.gpi.org	USA	GPI Headquarters 515 King Street, Suite 420 Alexandria, VA 22314 Phone: (703) 684-6359 Fax: (703) 684-6048 Andrew Bopp abopp@clarionmanagement.com	2 studies identified: None relevant to the project's goal
3	Standing Committee of the European Glass Industries (CPIV) http://www.cpivglass.be	Europe	89, avenue Louise B – 1050 Brussels Belgium Phone: + 32 (0)2/ 538 44 46 Fax: + 32 (0)2/ 537 84 69 info@cpivglass.be	No studies identified
4	British Glass http://www.britglass.co.uk	UK	9 Churchill Way Chapeltown, Sheffield S35 2PY Tel: +44 (0) 114 290 1850 Fax: +44 (0) 114 290 1851 Ben Stone, b.stone@britglass.co.uk	1 study identified (GL-2)
5	Das Aktionsforum Glasverpackung http://www.glasaktuell.de	Germany	Deisenfangstrasse 37-39 D-88212 Ravensburg Tel.: 0751 - 36 220 26 Fax: 0751 - 35 29 43 50 info@glasaktuell.de Heribert Streubel heribert.streubel@gga-ravensburg.de	1 study identified: Prognos GmbH, Institut für Energie und Umweltforschung Heidelberg, Gesellschaft: Ökobilanz für Getränkeverpackung II. Pack Force, and the German Federal Environment Agency.
6	REXAM http://www.rexam.com	UK/global	Burton Road, Monk Bretton, Barnsley, South Yorkshire S71 2QG, UK Phone: +44 (0)1226 719886 Fax: + 44 (0)1226 719111 Larissa Lauinger larissa.lauinger@rexam.com	1 study identified (GL-2)

7	Saint-Gobain **http://www.saint-gobain-conditionnement.com**	France/global	Compagnie de Saint-Gobain Les Miroirs 18, avenue d'Alsace 92400 Courbevoie France Phone: +33 1 47 62 30 00	No studies identified
8	the Department of Chemical Engineering at Loughborough University http://www.lboro.ac.uk/departments/cg/index.html	UK	Dr. David Edwards d.w.edwards@lboro.ac.uk	1 study identified (GL-11)

Plastics LCA contacts

Chalmers, Sweden
IVAM, The Netherlands
Boustead Consulting, UK
IFEU, Germany
O2, France
PE Europe, Germany
EMPA, Switzerland
2.-0 consultants, Denmark
Environment Agency, UK

The Association of Plastic Manufacturers in Europe (APME) – references directly on homepage
The Danish Plastics Association
Norwegian Plastics Industries Association (PIF)
British Plastics Federation (BPF)
The Finnish Plastics Association
Plastics Industries Association
Plast- och Kemibrancherna (PoK)
Norsk Hydro
SIS Eco-labelling
The European Council for Plasticisers and Intermediates (ECPI)

Aluminium LCA contacts

Contacted Aluminium institutions
The International Aluminium Institute, IAI, Global, www.world-aluminium.org/iai/index.html
European Aluminium Association (EAA), Europe, www.aluminium.org
The Aluminum Association (USA), North America, www.Aluminum.org
Australian Aluminium Council (AAC), Australia, www.aluminium.org.au
Gesamtverband der Aluminiumindustrie e.V., Europe, www.Aluinfo.de
Sekretariat for Aluminium & Miljø, Europe, www.alu-info.dk
Japan Aluminium Association, Asia, www.aluminum.or.jp

Institutions below refer to above-named main institutions:
Aluminium Association of Canada, North America
Aluminium Association of Greece, Europe
Aluminium Association of India, Asia
Aluminium Federation Ltd. (UK), Europe
Aluminium Federation of South Africa, Africa
Aluminiumindustriens Miljosekretariat, Europe
Aluminium Packaging Recycling Organisation (UK), Europe
Aluminium Verband Schweiz, Europe
Associaçao Brasileira do Aluminium, South America
Asociación para el Reciclado de Productos de Aluminio (ARPAL), Europe
Associazione Nazionale Industrie Metalli non Ferrosi (ASSOMET), Europe
Camera Argentina de la Industria del Aluminio y Metales Afines, South America
China Nonferrous Metals Industry Association - no website, Asia
Eurometaux, Europe
European Aluminium Association, Europe
European Aluminium Foil Association, Europe
Fabrimetal (Belgium), Europe
Genossenschaft Aluminium Recycling (Switzerland), Europe

Steel LCA contacts

Apeal - Association of European Producers of Steel for Packaging www.apeal.org

Arcelor - Arcelor Ugine Savoie
Env. Department
Blue Scope Steel
www.bluescopesteel.com
Level 11, 120 Collins Street
Melbourne, VIC 3000

Corus construction group
Corus Construction Centre

Corus R&D
Swinden Technology Centre
Moorgate
South Yorkshire S603AR
UK
www.corusconstruction.com

Eurofer- European Confederation of Iron and Steel Industries
Rue du Noyer, 211
B-1000 Brussels
www.eurofer.org

IISI- International Iron and Steel Institute
International Iron and Steel Institute
www.iisi.be

ISRI - Institute of Scrap Recycling Industries, Inc.
1325 G Street, NW, Suite 1000
Washington, DC 20005-3104
www.isri.org

Outokumpu steelOutokumpu Oyj, Riihitontuntie 7

PO Box 140, FI-02201 Espoo

Steel recycling institute -SRI www.recycle-steel.org

Wuppertal Institute for Climate, Environment & Energy
P.O. Box 100480
42004 Wuppertal

Aggregates LCA contacts

Organisation	Contact
NIRAS	PHe@NIRAS.dk
Statens Byggeforskningsinstitut	awd@sbi.dk
dk-Teknik	hks@dk-teknik.dk
Dansk Byggeri	info@danskbyggeri.dk
RT, Confederation of Finnish Construction Industries	http://www.rakennusteollisuusrt.fi/
CIF, Construction Industry Federation	www.cif.ie
Statsbygg	Norway
Sintef, civil & environmental engn	http://www.sintef.no/
GRIP	www.grip.no
EBA Entreprenørforeningen - Bygg og Anlegg	www.ebanett.no
Sveriges Byggindustrier	www.bygg.org
Construction Confederation	http://www.theCC.org.uk
Miljömärkningen	Sweden

General LCA organisations and national EPAs contacted

Chalmers, Civil Engineering, Sweden

Chalmers, Energy Technology, Sweden

COWI A/S, Denmark

FORCE Technology, Denmark

LCA 2.-0 consultants, Denmark

VTT Environment, Finland

Sintef, Civil & Environmental Engineering, Norway

Stiftelsen Østfold, Norway

CIT, Chalmers, Sweden

IVL, Sweden

Linköping University, Sweden

PE-Europe, Germany

IFEU - Institut für Energie und Umweltforschung Heidelberg, J Giegrich, Germany, http://www.ifeu.de/

Öko-Institut e.V. - Institut für angewandte Ökologie, Germany http://www.oeko.de/

Wuppertal Institut, Germany http://www.wupperinst.org/

Pré Consultants, Netherlands

IVAM, Netherlands http://www.ivambv.uva.nl/uk/

CML, Netherlands http://www.leidenuniv.nl/cml/

TNO , Netherlands

EMPA, Switzerland

Randa Group, Spain

O2 FRANCE, France

Five Winds International, Germany

Boustead Consulting, UK

Swedish EPA, Sweden www.environ.se

Swedish Ministry of Environment, Sweden http://www.miljo.regeringen.se/

Finnish EPA, Finland www.ymparisto.fi

Irish EPA, Ireland

UK Environment Agency, UK

BUND - Bund für Umwelt und Naturschutz Deutschland, Germany

WRAP - the Waste & Resources Action Programme, UK www.wrap.org.uk

ETH, Switzerland

BUWAL - Bundesamt für Umwelt, Wald und Landschaft (Swiss EPA), Switzerland

Danish EPA (Miljøstyrelsen), Denmark www.mst.dk

United Nations Environment Programme

PriceWaterhouse Coopers - ECOBILAN, France

UBA Umweltsbundesamt (German EPA), Germany

Bio Intelligence, Véronique Monier,– France

Sound Resource Management, Jeffrey Morris, USA

Yale University, Yale School of Forestry & Environmental Studies, Thomas Graedel, USA

Waste institutions and other organisations contacted

European Commission, DG Env, Otto Linher, waste division.

EPA websites from Sweden and Denmark

ISWA, International Solid waste association

Resource Recovery Forum, UK

Danish waste information centre, Susan Christensen www.affaldsinfo.dk

Norsas, Norsk kompetansesenter for avfall og gjenvinning, Norway (Norwegian competence centre for waste and recycling, www.norsas.no)

Norsk renholdsverks-forening (NRF), Norway. (Norwegian waste management association, www.nrfo.no)

RVF, Svenska Renhållningsverksföreningen, Sweden (Swedish waste management association) www.rvf.se

Nordisk videndeling om affald, (Nordic waste information sharing system) www.nordic-waste.info .

Afval Overleg Orgaan, Information center for waste in the Netherlands, Guus van den Berghe; Netherlands. www.aoo.nl

Appendix 3. Complete list of LCA references

Paper and Cardboard Selected LCA Case studies

Study no.: 1	Tillman, AM, Baumann, H, Eriksson, E, Rydberg, T (1991) Life Cycle analyses of selected packaging materials. Quantification and environmental loadings. (In Swedish: "*Miljön och förpackningarna*"), SOU, 1991:76
Waste stream	Corrugated board and paper board
Objective and comments	The study characterises the environmental profile of the life cycle of corrugated board and paper board for beverage packaging. The studied object is the life cycle of 1kg of corrugated board and of 1kg of paper board for beverage packaging.
Country/language	Sweden/Swedish
Conductor	Chalmers Industriteknik, CIT
Commissioner	Staten Offentliga Utredningar; Miljödepartementet

Study no.: 2	Dalager et al. (1995a-1995d); *Miljøøkonomi for papir- oq papkredsløb.* (Environmental economics of paper and cardboard circulation. Working reports (4 reports in total) 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
Waste stream	Corrugated cardboard, newspaper & magazines, and mixed paper
Objective and comments	Evaluation of the environmental performance of increased paper recycling. Recovery/disposal under different scenarios of the Danish production of used paper, 1995. End-of-line comparison – whole life cycle not included.
Country/language	Denmark/Danish with executive summaries in English
Conductor	dk-TEKNIK, Danish Technological Institute, Econet, National Environmental Research Institute
Commissioner	Danish Environmental Protection Agency

Study no.: 3	Virtanen, Y, Nilsson, S (1993) The environmental Impacts of waste paper recycling. IIASA, Laxembourg (Austria)
Waste stream	Mixture of 20% newsprint, 38% printing and writing, 20% liner board, 15% fluting, 7% folding boxboard, 1% household
Objective and comments	Comparison of total incineration vs. maximum recycling
Country/language	Austria, Finland, France, Italy, the Netherlands, Sweden, United Kingdom and Western Germany /English
Conductor	IIASA, International Institute for Applied Systems Analysis
Commissioner	No inf.

Study no.: 4	Kärnä, A., Engström, J., Kutinlahti, T. & Pajula, T. (1994); *Life cycle analysis of newsprint: European scenarios*. Paperi ja Puu - Paper and Timber 76(4): 232-237.
Waste stream	Newsprint, magazines
Objective and comments	Paper reuse vs. paper incineration to reduce landfilling. 1000 kg paper/yr delivered to consumers in Germany, 1990. Virgin paper imported from Finland.
Country/language	Austria, Finland, France, Italy, the Netherlands, Sweden, United Kingdom and Western Germany /English
Conductor	IIASA, International Institute for Applied Systems Analysis
Commissioner	No inf.

Study no.: 5	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, U.K. http://www.aylesford-newsprint.co.uk/pdf/lcs.pdf
Waste stream	Newsprint, magazines
Objective and comments	Paper reuse in UK vs. paper incineration in UK and recycling in other countries (the study adopts the perspective of the recycling company Aylesford, UK). Disposal of 1000 kg used newspapers and magazines. End-of-line comparison – whole life cycle not included.
Country/language	United Kingdom/English
Conductor	Ecobilan Group (Ecobalance UK)
Commissioner	the company Aylesford Newsprint Ltd. (ANL)

Study no.: 6	Grant, T., K. James, S. Lundie and K. Sonneveld (2001); *Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria*. Melbourne, EcoRecycle Victoria. Australia
Waste stream	Newsprint and cardboard packaging
Objective and comments	Evaluation of the environmental performance of paper recycling vs. landfilling (no scenario with incineration). Management of the recyclable fraction of newsprint paper & board packaging from the average Melbourne household in one week (ca. 3.64 kg on average). End-of-line comparison – whole life cycle not included.
Country/language	Australia/English
Conductor	CRC for Waste Management and Pollution Control, Centre for Waste and Water Technology at UNSW, National Centre for Design at RMIT, Centre for Packaging, Transportation and Storage at VUT acting on behalf of the Food and Packaging CRC.
Commissioner	EcoRecycle Victoria

Study no.: 7	Tiedemann, A., Klöpffer, W., Grahl, B. & Hamm, U. (2001); Life Cycle Assessments for Graphic Papers. Nr 2/2001, Umweltbundesamt, the German Federal Environmental Agency, Berlin, Germany. http://www.umweltbundesamt.de/uba-info-medien-e/mysql-media-detail.php3?Kennummer=1925
Waste stream	Graphic paper
Objective and comments	Identification of the disposal option(s) with lower environmental impacts. Studies the total production and processing of paper in Germany in 1995.
Country/language	Germany/English
Conductor	Federal Environmental Agency of Germany
Commissioner	Federal Environmental Agency of Germany

Study no.: 8	Environmental Defence (2002); *Lifecycle 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
Waste stream	Newsprint, corrugated board, CUK paperboard, SBS paperboard and office paper
Objective and comments	Comparison of virgin paper and recycled paper systems. Studied object: 1 tonne of newsprint/corrugated/cardboard/office paper handled for disposal/recycling
Country/language	USA/English
Conductor	The Paper Task Force: Duke University, the Environmental Defense Fund, Johnson and Johnson, McDonald's, the Prudential Insurance Company of America, and Time Inc.
Commissioner	No inf.

Study no.: 9	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 aspects of paper and cardboard recycling). Submitted for publication in February 2004 to the Danish Environmental Protection Agency within the series "Environmental Report" (In Danish).
Waste stream	Mixed paper, newsprint, and corrugated board
Objective and comments	Update of information on the environmental aspects of paper recycling and disposal. Studied object: In the scenarios with 100 % recycling and 100 % incineration: 1 kg of paper/board collected in Denmark in year 2001. In the rest of scenarios: total use of paper in Denmark in 2001.
Country/language	Denmark/Danish with exhaustive executive summary in English
Conductor	The Institute for Product Development and Danish Technological Institute
Commissioner	The Danish Environmental Protection Agency

Evaluated 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 grave 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, Göteborg, Sweden.

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Arena, U., Mastellone, M. L., Perugini F. & Clift, R. (2003); *Environmental Assessment of Paper Waste Management Options by means of LCA Methodology*. Submitted to I&EC Research

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Glass Selected LCA Case studies

Selected studies

Code	**Material**	**Authors (Year) Title, Publisher**	**Country**	**Status**
GL-1	Recycling of materials - including glass	Craighill,A., and Powell,J., (1996) Lifecycle assessment and economic evaluation of recycling: a case study. Resources, conservation and recycling, 17 (1996) 75-96 [BACKGROUND REPORT: Craighill,A., and Powell,J (1995) Lifecycle assessment and economic evaluation of recycling: a case study. CSERGE Working paper WM 95-05. ISSN: 0967-8875.Centre for Social and Economic Research on the Global Environment, University of East Anglia, and University College of London]	UK	Selected
GL-2	Glass packaging	Enviros (2003): Glass Recycling - Life Cycle Carbon Dioxide Emissions – A Life Cycle Analysis Report Prepared for British Glass by Enviros Consulting Ltd November 2003, CAN BR110 004	UK	Selected
GL-3	Waste packaging- including glass	Grant, T., K. James, S. Lundie and K. Sonneveld (2001); Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria. Melbourne, EcoRecycle Victoria. Australia	Australia	Selected
GL-4	Waste handling options - including glass	Muñoz I, Rieradevall J, Doménech X and Milà L (2004) LCA Application to Integrated Waste Management Planning In Gipuzkoa (Spain) Int J LCA 9 (4) 272-280 (2004) [BACKGROUND REPORT: LCA Group - Centre d'Estudis Ambientals - Universitat Autònoma de Barcelona (2002) LCA applied to different alternatives for the management of MSW and sewage sludge in the Waste Management Plan of Gipuzkoa for 2005-2016. (In Spanish)]	Spain	Selected
GL-5	Waste packaging- including glass	Pommer, K.; Wesnaes, M.S.; Madsen, Chr. (1995) Environmental survey of Packaging Systems for Beer and Soft Drinks – Main Report (in Danish) Danish EPA (Work Report no. 72)	Denmark	Selected
GL-6	Waste packaging- including glass	RDC Environment et Coopers & Lybrand - Belgium (1997) Eco-balances for policy-making in the domain of packaging and packaging waste. European Commission , DG Environment. Reference no.: B4-3040/95001058/MAR/E3	(EU)	Selected
GL-7	Waste packaging- including glass	RDC-Environment and Pira International. (2003) Evaluation of Costs and Benefits for the Achievement of Reuse and the Recycling Targets for the Different Packaging Materials in the Frame of the Packaging and Packaging Waste Directive 94/62/EC. (Final consolidated report) Brussels: European Commission, 2003. http://europa.eu.int/comm/environment/waste/studies/packaging/costsbenefits.pdf	(EU)	Selected
GL-8	Materials recycling, including glass	Smith A, Brown K, Ogilvie S, Rushton K and Bates J (2001). Waste management options and climate change. Final report to the European Commission, DG Environment. http://europa.eu.int/comm/environment/waste/studies/climate_change.htm	(EU)	Selected
GL-9	Packaging waste- including glass	Tillman A-M, Baumann H, Eriksson E and Rydberg T (1991): Packaging and the Environment – Life Cycle assessments of packaging materials – calculations of environmental impact, Statens offentliga utredningar 1991:77, Miljødepartementet.	Sweden	Selected
GL-10	Waste packaging- including glass	USEPA (2002) Solid Waste Management and Greenhouse Gases. A Life-Cycle Assessment of Emissions and sinks. 2nd edition EPA530-R-02-006, May 2002.	USA	Selected

GL-11	Glass packaging	Edwards, D.W. & J. Schelling, J. (1999): Municipal Waste Life Cycle Assessment Part 2: Transport Analysis and Glass Case Study Process Safety and Environmental Protection Print ISSN: 0957-5820 | Electronic ISSN: 1744-3598 Volume: 77 | Issue: B5 Cover date: September 1999 Page(s): 259-274	UK	Selected

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Packaging-including glass	Frees N, Rydberg A and Ekvall T (1998): Life Cycle Assessment of packaging Systems for Beer and Soft Drinks – Main Report, Technical Report no. 399, Danish Environmental Protection Agency.
Packaging-including glass	Habersatter, K.; Fecker, I.; Dall`aqua, S.; Fawer, M.; Fallscher, F.; Förster, R.; Maillefer, C.; Ménard, M.; Reusser, L.; Som, C.; Stahel, U.; Zimmermann, P. (1998): Ökoinventare für Verpackungen. ETH Zürich und EMPA St. Gallen für BUWAL und SVI, Bern. In: Bundesamt für Umwelt, Wald und Landschaft (Hrsg.): Schriftenreihe Umwelt Nr. 250/Bd.I und II. 2nd edition Bern 1998 (1st edition 1996) (In German, an English version is also available).
Packaging-including glass	Lox F (1994)Waste Management – Life Cycle Analysis of Packaging, VUB, VITO, BPI, May 1994. Final Report of Contract Number B4-3040/014093 for European Commission DGXI/A4, Belgium
Glass packaging	Mata, T.M. & Costa, C.A.V. (2001): Life Cycle Assessment of Different Reuse Percentages for Glass Beer Bottles. InternationalJournal of LCA 6 (5) 307-319 (2001)
MSW - including glass	Mendes, MR; Aramaki, T Hanaki, K.: Comparison of the environmental impacts of incineration and landfilling in São Paulo City as determined by LCA Resources, Conservation and Recycling 41 (2004) 47-63
Packaging-including glass	Pira & Ecolas (2005) Study on the implementation of the Packaging Directive and options to strengthen prevention and re-use Final Report. European Commission, report 03/07884/AL. In particular are of interest Appendixes 1 and 2. http://europa.eu.int/comm/environment/waste/packaging_index.htm
Packaging-including glass	Plinke, E., Schonert, M., Meckel, H., Detzel., A., giegrich, J., Fehrenbach, H., Ostermayer, A., Schorb, A., Heinisch, J., Luxenhofer, K., Schmitz, S (2000) Ôkobilanz für Getränkeverpackungen II (LCA of drinks packaging II). (‚UBA-II report') Texte 37/00, Umweltbundesamt, Berlin. (German Federal Environment Agency) (In German). Http://www.umweltbundesamt.de/uba-info-daten/daten/bil.htm
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PL05	Ekvall T, Person L, Rydbaerg A, Widheden J, Frees N, Nielsen P H, Weidema B and Wesnaes M (1998): Life Cycle Assessment of packaging Systems for Beer and Soft Drinks - Main Report, Environmental Report no. 399, Danish Environmental Protection Agency.
PL06	Person L, Ekvall T, Weidema B (1998): Life Cycle Assessment of packaging Systems for Beer and Soft Drinks - Refillable PET Bottles, Technical Report no. 5, Environmental Report no. 404, Danish Environmental Protection Agency.
PL07	Person L, Ekvall T, Weidema B (1998): Life Cycle Assessment of packaging Systems for Beer and Soft Drinks - Disposable PET Bottles, Technical Report no. 6, Environmental Report no. 405, Danish Environmental Protection Agency.
PL08	Tillman A-M, Baumann H, Eriksson E and Rydberg T (1991): Packaging and the Environment - Life Cycle assessments of packaging materials - calculations of environmental impact, Statens offentliga utredningar 1991:77, Miljødepartementet.
PL09	Rydberg T, Ekvall T, Kullman, M (1993) Recycling, incineration or landfilling of polyethylene - a comparative environmental assessment, ReC'93, Geneva, Jan. 1993.
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PL14	O'Neill T J (2003): Life Cycle Assessment and Environmental Impact of Plastic Products, ISBN 1-85957-364-9 (book)
PL15	Arena U, Mastellone M L, Perugini F (2003): Life Cycle Assessment of a Plastic Packaging Recycling System. Int. J. LCA 2003, 8 (2), 92-98.
PL37	Life Cycle Assessment of Polyvinyl Chloride and Alternatives, Summary Report, 2001, Department of the Environment, Transport and the Regions, London
PL41	Ross, S.; Evans, D., 2003, The environmental effect of reusing and recycling a plastic-based packaging system, Journal of Cleaner Production, Vol.11 Issue.5, 561-571
PL42	Perugini, Floriana; Mastellone, Maria Laura; Arena, Umberto, , Environmental aspects of mechanical recycling of PE and PET: A life cycle assessment study, Progress in Rubber Plastics Recycling Technology, Vol.20 Issue.1
PL44	Song, Hyun-Seob; Hyun, Jae Chun, 1999, A study on the comparison of the various waste management scenarios for PET bottles using the life-cycle assessment (LCA) methodology, Resources, Conservation and Recycling, Vol.27 Issue.3, 267–284
PL45	Leaversuch, Robert D, 1995, Cradle-to-grave environmental assessments favour plastics' use in many markets, Modern Plastics, Vol.72 Issue.8
PL46	Moelgaard, Claus, 1995, Environmental impacts by disposal of plastic from municipal solid waste, Resources, Conservation and Recycling, Vol.15 Issue.1, 51-63

PL47	Parker, Gary, 2005, Threat of more eco pressure, Packaging Magazine, Vol.8 Issue.3
PL51	Joosten, L.A.J. M.P. Hekkert a, E. Worrell, 2000, Assessment of the plastic flows in The Netherlands using STREAMS, Resources, Conservation and Recycling 30 (2000) 135–161
PL52	Life Cycle Assessment of Polyvinyl Chloride and Alternatives, Final Report, 2000, Department of the Environment, Transport and the Regions, London
PL54	Ökobilanz für das Recycling von in Verkehr gebracten Poyluretahn-Schaumdosen nach PDR-Verfahren, Kurzfassung, PDR Recycling GmbH + Co KG, http://www.pdr.de/
PL75	Plastic Shopping Bags –Analysis of Levies and Environmental Impacts, 2002, Prepared in association with RMIT Centre for Design and Eunomia Research and Consulting Ltd, Environment Australia
PL76	Tillberg, Sibell, 2001, Livscykelanalys på Restproduktshantering, EXAMENSARBETE, TRITA-KET-IM 2001:5
PL77	Zhang, Hong-Chao, Frederick Ling, 1999, A Decision-Making Model for Materials Management of End-of-Life Products in the Pantex Plant, Amarillo National Resource Center for Plutonium, ANRCP-1999-27
PL78	Dhingra, Rajive, Jonathan G. Overly and Gary A. Davis, Sujit Das, Stan Hadley and Bruce Tonn, 2000, A Life-Cycle-Based Environmental Evaluation, Materials in New Generation Vehicles, SAE TECHNICAL PAPER SERIES 2000-01-059
PL79	Shibasaki, M., Kupfer, T., Wolf, M.-A., Eyerer, P, 2004, Recycling Concept for Contaminated Plastic Materials - A LCA Case Study, In: 6th International Conference on EcoBalance, Tsukuba, 2004
PL81	Shibasaki, M.; Herrmann, C.; Warburg, N.; Eyerer, P., 2003, "Challenges and Practical Approach of End of Life Calculation Methods in Life Cycle Assessment", IUMRS-ICAM2003, The 8th IUMRS International Conference on Advanced Materials, Yokohama, Japan

PL83	Wollny, Volrad, Martin Schmied, 2000, Assessment of Plastic Recovery Options , European Environmental Bureau (EEB) Brussels, http://www.eeb.org/publication/2000/publications2000.htm
PL87	Hunt, Robert G., 1995, LCA considerations of solid waste management alternatives for paper and plastics, Resources, Conservation and Recycling, Vol.14 Issue.3-4 , 225-231
PL88	Worlds largest PET Life Cycle Assessment - One-way PET levels with refillable glass, Summary, 2004, Conducted by IFEU in Heidelberg, Germany for the German Market,
PL91	James, Karli and Tim Grant, 2005, LCA of Degradable Plastic Bags, Centre for Design, February 2005

Aluminium

Selected LCA Case studies

ID	Material	Authors (Year), Title, Publisher	Country
AL-1	Packaging systems - including aluminium	**Ryberg, A.; Ekvall, T.; Person, L. and Weidema B. (1998)**: Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks – Technical Report 3, Danish EPA (Environmental Project no. 402) http://www.mst.dk/udgiv/Publications/1998/87-7909-023-0/pdf/87-7909-023-0.PDF [MAIN REPORT: Ekvall T, Person L, Ryberg A, Widheden J, Frees N, Nielsen P H, Weidema B and Wesnaes M (1998), Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks – Main Report 3, Danish EPA (Environmental Project no. 399)	Denmark
AL-2	Packaging waste- including aluminium	**Tillman A-M, Baumann H, Eriksson E and Rydberg T (1991)**: Packaging and the Environment – Life Cycle assessments of packaging materials – calculations of environmental impact, Statens offentliga utredningar 1991:77, Miljødepartementet.	Sweden
AL-3	Waste packaging- including aluminium	**US EPA (2002)** Solid Waste Management and Greenhouse Gases. A Life-Cycle Assessment of Emissions and sinks. 2nd edition EPA530-R-02-006, May 2002	USA
AL-4	Waste packaging- including aluminium	**RDC-Environment and Coopers & Lybrand - Belgium (1997)** Eco-balances for policy-making in the domain of packaging and packaging waste. European Commission, DG Environment. Reference no.: B4-3040/95001058/MAR/E3	(EU)
AL-5	Waste packaging- including aluminium	**Grant, T., K. James, S. Lundie and K. Sonneveld (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	Australia

AL-6	Waste packaging- including aluminium	**RDC-Environment and Pira International. (2003)** Evaluation of Costs and Benefits for the Achievement of Reuse and the Recycling Targets for the Different Packaging Materials in the Frame of the Packaging and Packaging Waste Directive 94/62/EC. (Final consolidated report) Brussels: European Commission, 2003. http://europa.eu.int/comm/environment/waste/studies/packaging/costsbenefits.pdf	(EU)
AL-7	Materials recycling, including aluminium	**Smith A, Brown K, Ogilvie S, Rushton K and Bates J (2001)**, Waste management options and climate change. Final report to the European Commission, DG Environment. http://europa.eu.int/comm/environment/waste/studies/climate_change.htm	(EU)
AL-8	Waste packaging- including aluminium	**Pommer, K.; Wesnaes, M.S.; Madsen, C; Larsen, MH (1995)** Environmental assessment of packagings for beer and soft drinks –Sub report 3: aluminium cans (in Danish) Danish EPA (Work Report no. 72) [MAIN REPORT: Pommer, K.; Wesnaes, M.S. (1995) Environmental survey of Packaging Systems for Beer and Soft Drinks (in Danish) Danish EPA (Main Report), EPA Work Report no. 62]	Denmark
ID	**Material**	**Authors (Year), Title, Publisher**	**Country**
AL-9	Recycling of aluminium	**Edwards, D.W. and Schelling, J. (1996)**: Municipal Waste Life Cycle Assessment Part 1 and Aluminium Case Study, Transactions of the Institution of Chemical Engineers, B, 74, 1996, pp 205-222, ISSN 0957 5820	UK
AL-10	Packaging systems - including aluminium	**Schonert, M.; Motz, G.; Meckel, H.; Detzel, A.; Giegrich, J.; Ostermayer, A.; Schorb, A.; Schmitz, S. (2002)**: Ecobalance for beverage packaging - UBA II/ Phase 2, German EPA (in German) http://www.uba.de/uba-info-medien/index.htm [Plus one main report and two technical reports from 2000]	Germany
AL-11	Recycling of materials - including aluminium	**Craighill, A. and Powell, J., (1996)** Lifecycle assessment and economic evaluation of recycling:a case study. Resources, conservation and recycling, 17 (1996) 75-96 http://www.uea.ac.uk/env/cserge/pub/ext/295.htm [BACKGROUND REPORT: Craighill, A. and Powell, J (1995) Lifecycle assessment and economic evaluation of recycling: a case study. CSERGE Working paper WM 95-05. ISSN: 0967-8875.Centre for Social and Economic Research on the Global Environment, University of East Anglia and University College of London]	UK

Other evaluated references - rejected but useful for discussions

Material	**Authors (Year), Title, Publisher**
Aluminium in packaging	**BUWAL (1998)** Bundesamt für Umwelt, Wald und Landschaft (BUWAL) (Swiss Federal Office of Environment, Forests and Landscape): “Eco-inventories for Packagings - Volume 1 and Volume 2 (BUWAL 250/I/II)” (in German), BUWAL, Bern, Switzerland Incl. earlier reports (BUWAL 1996)
Aluminium in packaging	**BUWAL (1990)** Bundesamt für Umwelt, Wald und Landschaft (BUWAL) (Swiss Federal Office of Environment, Forests and Landscape): “Eco-balances for Packagings - Status 1990 (BUWAL 125)” (in German), BUWAL, Bern, Switzerland Incl. same reports in German (BUWAL 1996)

Aluminium in general	**Vroonhof et al. 2002** (Jan Vroonhof, Anne Schwenke, Harry Croezen, Berend Potjer), all "CE - Solutions for environment, economy and technology" (Dec. 2002) Legislation using LCA concerning Aluminium
Aluminium in general	**International Aluminium Institute (March 2003)** Life cycle assessment of aluminium: Inventory data for the worldwide primary aluminium industry Int. Aluminium Institute (review/comments by panel with Five Winds Inst. as leader)
Aluminium in general	**EAA (April 2000a)** Environmental Profile Report for the European Aluminium Industry European Aluminium Association, EAA (review by I. Boustead)
Aluminium in general	**EAA (April 2000b)** Guidelines for Life Cycle Assessment (LCA) of Aluminium Products European Aluminium Association, EAA
Aluminium in general	**EAA (April 2000c)** Key features how to treat aluminium in LCAs, with special regard to recycling issues, European Aluminium Association, EAA
Packaging incl. aluminium	**Pira & Ecolas (2005)** Study on the implementation of the Packaging Directive and options to strengthen prevention and re-use Final Report. European Commission (DG Environment) Report 03/07884/AL. In particular are of interest Appendices 1 and 2 (http://europa.eu.int/comm/environment/waste/ packaging_index.htm)

Steel

Selected LCA Case studies

ID	Material	Authors (Year) Title, Publisher	Country
ST-1	Recycling of materials - including steel	Craighill,A., and Powell,J., (1996) Lifecycle assessment and economic evaluation of recycling:a case study. Resources, conservation and recycling, 17 (1996) 75-96 [BACKGROUND REPORT: Craighill,A., and Powell,J (1995) Lifecycle assessment and economic evaluation of recycling:a case study. CSERGE Working paper WM 95-05. ISSN: 0967-8875.Centre for Social and Economic Research on the Global Environment, University of East Anglia, and University College of London]	UK
ST-2	Packaging waste- including steel	Tillman A-M, Baumann H, Eriksson E and Rydberg T (1991): Packaging and the Environment – Life Cycle assessments of packaging materials – calculations of environmental impact, Statens offentliga utredningar 1991:77, Miljødepartementet.	Sweden

ST-3	Waste packaging - including steel	Grant, T., K. James, S. Lundie and K. Sonneveld (2001); Stage 2 Report for Life Cycle Assessment for Paper and Packaging Waste Management Scenarios in Victoria. Melbourne, EcoRecycle Victoria. Australia Including Appendix Q: Steel-tin plate chapter http://www.ecorecycle.vic.gov.au/asset/1/upload/Stage_2_Report_for_Life_Cycle_Assess_for_Packaging_Waste_Mg.pdf	Australia
ST-4	Waste handling options - including steel	Muñoz I, Rieradevall J, Doménech X and Milà L (2004) LCA Application to Integrated Waste Management Planning In Gipuzkoa (Spain) Int J LCA 9 (4) 272-280 (2004) [BACKGROUND REPORT: LCA Group - Centre d'Estudis Ambientals - Universitat Autònoma de Barcelona (2002) LCA applied to different alternatives for the management of MSW and sewage sludge in the Waste Management Plan of Gipuzkoa for 2005-2016. (In Spanish)]	Spain
ST-5	Waste packaging - including steel	Pommer, K.; Wesnaes, M.S.; Madsen, C, Larsen, MH (1995) Environmental assessment of packagings for beer and soft drinks – Subreport 4: steel cans (in Danish) Danish EPA (Work Report no. 73) [MAIN REPORT: Pommer, K.; Wesnaes, M.S.; Madsen, Chr. (1995) Environmental survey of Packaging Systems for Beer and Soft Drinks (in Danish) Danish EPA (Work Report no. 72)]	Denmark
ST-6	Waste packaging - including steel	USEPA (2002) Solid Waste Management and Greenhouse Gases. A Life-Cycle Assessment of Emissions and sinks. 2nd edition EPA530-R-02-006, May 2002.	USA
ST-7	Materials recycling, including steel	Smith A, Brown K, Ogilvie S, Rushton K and Bates J (2001). Waste management options and climate change. Final report to the European Commission, DG Environment. http://europa.eu.int/comm/environment/waste/studies/climate_change.htm	(EU)
ST-8	Waste packaging - including steel	RDC Environment et Coopers & Lybrand - Belgium (1997) Eco-balances for policy-making in the domain of packaging and packaging waste. European Commission , DG Environment. Reference no.: B4-3040/95001058/MAR/E3	(EU)
ST-9	Waste packaging - including steel	RDC-Environment and Pira International. (2003) Evaluation of Costs and Benefits for the Achievement of Reuse and the Recycling Targets for the Different Packaging Materials in the Frame of the Packaging and Packaging Waste Directive 94/62/EC. (Final consolidated report) Brussels: European Commission, 2003. http://europa.eu.int/comm/environment/waste/studies/packaging/costsbenefits.pdf	(EU)

Other references on Steel LCA – rejected but useful for discussions

Material	Authors (Year) Title, Publisher
Recycling of materials, including steel	ADEME and BIO INTELLIGENCE SERVICE S. A..(2002). Environmental assessment of recycling channels: Inventory of'currently available LCA knowledge. (Bilan environnemental sur les filières de recyclage: l'état des connaissances ACV). Ref. 4362. Paris: Ademe, (In French).
Scrap disposal LCA	Afval Overleg Orgaan (2002) Environmental impact report for the National Waste Management Plan. Subreport A22: shredder waste. (Milieueffectrepport Landelijk Afvalbeheerplan. Achtergronddocument A22, Uitwerking 'Shredderafval'.(In Dutch) www.aoo.nl
Recycling- including steel	Denison, R (1996) Environmental life-cycle comparisons of recycling, landfilling and incineration. A review of recent studies. Annu.Rev.Environ. 1996, 21:191-237 www.annurev.org
Steel	E. C. Teixeira, R. B. Binotto, J. D. Sanchez, D. Migliavacca and J. M. G. Fachel (1999) Environmental assessment and characterization of residues from coal processing and steel industry activities. Fuel, Volume 78, Issue 10, August 1999, Pages 1161-1169
Steel, buildings	Eaton, K and Amato, A (1998)., A comparative environmental life cycle assessment of modern office buildings. Available from the Steel Construction Institute, Silwood Park, Ascot, SL5 7QN, UK. Telephone: (01344) 623345, Fax: (01344) 622944. Publication reference P182.
Packaging - including steel	Frees N, Rydberg A and Ekvall T (1998): Life Cycle Assessment of packaging Systems for Beer and Soft Drinks – Steel cans, Technical Report no. 4, Environmental Report no. 403, Danish Environmental Protection Agency. [MAIN REPORT: Ekvall T, Person L, Rydbaerg A, Widheden J, Frees N, Nielsen P H, Weidema B and Wesnaes M (1998): Life Cycle Assessment of packaging Systems for Beer and Soft Drinks – Main Report, Environmental Report no. 399, Danish Environmental Protection Agency]
Steel	Geldermann, J., Spengler, T. and Rentz, O (2000) Fuzzy outranking for environmental assessment. Case study: iron and steel making industry. Fuzzy Sets and Systems, Volume 115, Issue 1, 1 October 2000, Pages 45-65
Packaging - including steel	Habersatter, K.; Fecker, I.; Dall`aqua, S.; Fawer, M.; Fallscher, F.; Förster, R.; Maillefer, C.; Ménard, M.; Reusser, L.; Som, C.; Stahel, U.; Zimmermann, P. (1998): Ökoinventare für Verpackungen. ETH Zürich und EMPA St. Gallen für BUWAL und SVI, Bern. In: Bundesamt für Umwelt, Wald und Landschaft (Hrsg.): Schriftenreihe Umwelt Nr. 250/Bd.I und II. 2nd edition Bern 1998 (1st edition 1996) (In German, an English version is also available).

Steel, buildings	Joensson, A, Bjoerklund, T, Tillman AM (1998) LCA of concrete and steel frames . 3 LCA (4) 216-224 [Björklund T, Jönsson Å, Tillman, A-M. LCA of building frame structures – Environmental Impact over the Life Cycle of Concrete and Steel Frames. TEP Report 1996:8, Göteborg, Sweden.]
Packaging - including steel	Lox F (1994)Waste Management – Life Cycle Analysis of Packaging, VUB, VITO, BPI, May 1994. Final Report of Contract Number B4-3040/014093 for European Commission DGXI/A4, Belgium
Steel packaging	Manuilova, A (2003) LIFE CYCLE ASSESSMENT OF INDUSTRIAL PACKAGING FOR CHEMICALS. Akzo Nobel Surface Chemistry AB and Chalmers University of Technology. February 2003. Msc Thesis, Chalmers University. http://www.dantes.info/Publications/Publication-doc/Packaging-public.pdf
Steel	Marukawa, K and Edwards, KL (2001) Development of iron and steel into eco-material Materials & Design, Volume 22, Issue 2, April 2001, Pages 133-136
Steel	Michaelis, P., Jackson, T., and Clift, R. (1998) Exergy analysis of the life cycle of steel. Energy, Volume 23, Issue 3, March 1998, Pages 213-220
Steel	OutoKumpu (2005) Environmental declaration of cold rolled 1.4301 Stainless Steel. Outokompu Stainless AB,Avesta research centre, Sweden.
Steel in buildings	Petersen, AK and Solberg, B (2002) Greenhouse gas emissions, life-cycle inventory and cost-efficiency of using laminated wood instead of steel construction.: Case: beams at Gardermoen airport Environmental Science & Policy, Volume 5, Issue 2, April 2002, Pages 169-182
Packaging - including steel	Pira & Ecolas (2005) Study on the implementation of the Packaging Directive and options to strengthen prevention and re-use Final Report. European Commission, report 03/07884/AL. In particular are of interest Appendixes 1 and 2. http://europa.eu.int/comm/environment/waste/packaging_index.htm
Packaging - including steel	Plinke, E., Schonert, M., Meckel, H., Detzel., A., giegrich, J., Fehrenbach, H., Ostermayer, A., Schorb, A., Heinisch, J., Luxenhofer, K., Schmitz, S (2000) Ôkobilanz für Getränkeverpackungen II (LCA of drinks packaging II). (‚UBA-II report') Texte 37/00, Umweltbundesamt, Berlin. (German Federal Environment Agency) (In German). http://www.umweltbundesamt.de/uba-info-daten/daten/bil.htm
Steel LCA	Scaife, P , Nunn, J ., Cottrell, A., Wibberley, L.(2002) Towards sustainable steelmaking – an LCA perspective. ISIJ International, vol.42, supplement pp s5-s9. [Background ACARP II reports: http://ciss.com.au/ref/static/reports/public/acarp/acarp2.html]

Steel	Sunér, Maria. ”Life Cycle Assessment of Aluminium, Copper and Steel”, M.Sc.Thesis. Gothenburg, Sweden. May 1996 . ISSN K100-9560
Steel	T. Spengler, J. Geldermann, S. Hähre, A. Sieverdingbeck and O. Rentz (1998) Development of a multiple criteria based decision support system for environmental assessment of recycling measures in the iron and steel making industry, Journal of Cleaner Production, Volume 6, Issue 1, 1998, Pages 37-52
Steel, ELV	Ugaya, Cássia; Walter, Arnaldo (2004) Life Cycle Inventory Analysis – A Case Study of Steel Used in Brazilian Automobiles (6 pp) 9 LCA (6) 365-370 (2004)
Steel in buildings	Urie; Dagg (2004) Development of a life cycle assessment (LCA) based decision-making tool for the assessment of building products. Journal of environmental assessment policy and management [1464-3332] vol: 6 iss: 2 pg: 153

Wood

Selected LCA Case studies

Petersen, Ann Kristin; Solberg, Birger, 2002, Greenhouse gas emissions, life-cycle inventory and cost-efficiency of using laminated wood instead of steel construction. : Case: beams at Gardermoen airport, Environmental Science & Policy 5 (2002) 169–182,

Sathre, R.; L. Gustavsson, K. Pingoud, 2004, Greenhouse gas balance implications of recovered wood in Sweden and Finland In: Management of recovered wood recycling, bioenergy and other options, Christos Gallis, (editor) - Thessaloniki, 22-24 April

Scharai-Rad, Mohammad, Johannes Welling, 2002, Environmental and energy balances of wood products and substitutes, FAO - Food and Agriculture Organization of the United Nations, Rome 2002

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Number	Authors (Year) Title, Publisher	Language
WO100	Nebel, B. et. al., 2002, Ökobilanzierung Holzfussböden, Holzforschung München - HFM, Technische Universität München, ISBN 3-89675-975-2	German
WO101	Frühwald, A., 1996, Querschittsanalyse zur Ökologischer Bilanzierung von Holzprodukten in Deutschland, Europa und Nordamerika, Ordinariat für Holztechnologie der Universität Hamburg und Institut für Holzforschung der Universität München	German
WO11	Speckels, L., 2001, Ökologischer Vergleich verschiedener Verwertungs- und Entsorgungswege für Altholz, Mitteilungen der Bundesforschungsanstalt für Forst- und Holzwirtschaft, Germany, no. 205, Hamburg, Germany, BFH/Wiedebusch, ISSN: 0368-8798, 2001, 413 p	German
WO17	Petersen, Ann Kristin; Solberg, Birger, 2004, Greenhouse Gas Emissions and Costs over the Life Cycle of Wood and Alternative Flooring Materials, Climatic Change 64: 143–167, 2004, Kluwer Academic Publishers.	English
WO18	Anon, 1990, Oekoprofil von Holz, Untersuchungen zur oekobilanz von holz als baustoff, Bundes amt für Konjunkturfragen	German
WO19	Reijnders, L.; Huijbregts, M.A.J., 2003, Choices in calculating life cycle emissions of carbon containing gases associated with forest derived biofuels, Journal of Cleaner Production, Elsevier	English
WO21	Betz M, Coen D, Deimling S and Kreissig J (2002), Ökobilanz-Bausteine. Thermische Verwertung von Holzprodukten, PE Europe report	German
WO38	Anon, 2004, An analysis of the methods used to address the carbon cycle in wood and paper product LCA studies, An Analysis of the Methods Used to Address the Carbon Cycle in Wood and Paper Product LCA Studies, Issue.04	English
WO39	Reijnders, L.; Huijbregts, M.A.J., 2003, Choices in calculating life cycle emissions of carbon containing gases associated with forest derived biofuels, Journal of Cleaner Production, Vol.11 Issue.5, 527–532	English
WO40	Aldentun, Y., 2002, Life cycle inventory of forest seedling production - from seed to regeneration site, Journal of Cleaner Production, Vol.10 Issue.1	English

WO56	Merl, A; Anders Evald, Francesca Gambineri, Catharina Hohenthal, Gerfried JUNGMEIER, Paul Koukos, Fred McDarby, Ann-Kristin Peterson, George Skodras, Kostas Spanos, Lutz Speckels, Sandra Springer, Angelika Voss, Frank Werner, 2001, Information about waste management options in Europe A working document compiled during COST Action E9	English
WO57	Jungmeier, G., A. Merl, C. Gallis, C. Hohenthal, F. McDarby, A.K. Petersen, K. Spanos: "End of Use and End of Life Aspects in LCA of Wood Products - Selection of Waste Management Options and LCA Integration." In: Achievements of COST Action E9 Working Group 3	English
WO58	Chris Van Riet, 2004, Sustainable use of wood for products and energy. Conflict or opportunity?	English
WO59	Sustainable use of natural resources along the life-cycle of wood-based products, 2002, A joint contribution of the European Forestry and Forest-based Industries to the Thematic Strategy on “Sustainable use of resources”, 7th August 2002	English
WO61	Hunt, Robert G. et.al ., 2004, An analysis of the methods used to address the carbon cycle in wood and paper product LCA studies, Special report no. 04-03 AUGUST 2004, Franklin Associates, Ltd., Prairie Village, Kansas	English
WO63	Taylor, J., K Van Langenberg, 2003, Review of the Environmental Impact of Wood Compared with Alternative Products Used in the Production of Furniture, Forest & Wood Products Research & Development Corporation, Victoria Australia, Project no: PN03.2103	English
WO64	Townsend, Phil and Chris Wagner, 2002, Timber as a Building Material - synthetic building materials, http://www.nafi.com.au/files/library/	English
WO65	Eriksson, O., B. Frostell, A. Bjo¨rklund, G. Assefa, J.-O. Sundqvist, J. Granath, M. Carlsson, A. Baky, L. Thyselius, 2002, ORWARE—a simulation tool for waste management, Resources, Conservation and Recycling 36 (2002) 287–307	English
WO66	COST ACTION E22: Environmental optimisation of wood protection, STATE OF THE ART REVIEWS, 2000, Proceedings of a Workshop held at Godz Martuljek, Ljubljana, Slovenia on 2-5 July 2000	English

WO67	Reid, Hannah, Saleemul Huq, Aino Inkinen, James MacGregor, Duncan Macqueen, James Mayers, Laurel Murray and Richard Tipper, 2004, Using wood products to mitigate climate change: a review of evidence and key issues for sustainable development, January 2004	English
WO69	Kozak, Robert, Christopher Gaston, 2001, Life Cycle Analysis, Forintek Canada Corp. Presented at the Workshop on Climate Change, Carbon and Forestry Orcas Island, Washington, November 13-16, 2001	English
WO70	Barbosa, J. C.; Ino, A; Shimbo, I., 2000, Sustainable indicators in the productive cycle of reforestated wood housing, World Conference on Timber Engineering, Whistler Resort, British Columbia, Canada, July 31 - August 3, 2000	English
WO72	Frühwald, A., J. Hasch, Un-dated, Life Cycle Assessment of Particleboards and Fibreboards, http://oekobilanzen-holz.de	English
WO93	Jungmeier, G. , 2004, Greenhouse gas emissions of energy generation from recovered wood - a comparison to fossil energy systems. In: Management of recovered wood recycling, bioenergy and other options, Christos Gallis, (editor) - Thessaloniki, 22-24 April	English
WO94	Energy and the Environment in residential construction, Sustainable Building Series No. 1, 2004, A publication of the Canadian Wood Council, http://www.cwc.ca/publications/PDFs/	English
WO95	Arno Frühwald and Birger Solberg (editors), 1995, Life-Cycle Analysis - a Challenge for Forestry and Forest Industry, Proceedings 8, 1995, ISBN: 952-9844-16-6, ISSN: 1237-8801, Proceedings of the International Workshop, organised by the European Forest Institute and Federal Research Centre for Forestry and Forest Products	English
WO97	Massivträ Handboken, http://www.solidwood.nu/sv/framedef.html	Swedish
WO99	Borg, M, 2001, Environmental Assessment of Materials, Components and Buildings, Doctoral Thesis, Kungl Tekniska Högskolan, ISBN 91-7283-159-6	English

Aggregates Selected LCA Case studies

ID	Material	Authors (Year), Title, Publisher	Country	Comment
AG-1	Construction and demolition waste	**Sara, B.; Antonini, E. and Tarantini, M. (2000)** Application of Life Cycle Assessment (LCA) methodology for valorization of building demolition materials and products Proceedings of SPIE - The International Society for Optical Engineering 9 p.	Italy/USA	via broad Internet search
AG-2	Construction and demolition waste	**Craighill, A. and Powell, J.C. (1999)** A Life Cycle Assessment and Evaluation of Construction and Demolition Waste Working paper of CSERGE http://www.uea.ac.uk/env/cserge/pub/wp/wm/wm_1999_03.pdf	UK	via broad Internet search

Aggregates ~ Other references - rejected but useful for discussions

ID	Material	Authors (Year), Title, Publisher	Country & found via	Conclusion / preference
AG-3	Aggregates in general	**Winter, M.G. and Henderson, C. (2003):** Estimates of the quantities of recycled aggregates in Scotland Engineering Geology, journal	UK, DADS	Recycling, high potential for increased recycling
AG-4	Aggregates in general	**Myer, A. and Chaffee, Ch. (1997):** Life-cycle analysis for design of the Sydney Olympic stadium. Renewable Energy	Australia, DADS	
AG-5	Slag	**Katsikaris, K.; Voutsas, E.; Magoulas, K.; Andronikos, G. and Stamataki, S. (2002):** Recycling ferrous-nickel slag in blast cleaning. Waste Management and Research, 10p.	Greece, DADS	
AG-6	Construction materials	**Horvath, A. (2004):** Construction materials and the environment Annual Review of Environment and Resources	mostly USA, DADS	Recycling presumed preferable
AG-7	Recycled materials in buildings	**Laufenberg, Th. (1996):** The Future of recycled material usage in building applications: Summary of conference viewpoints. Forest Products Society, US	broad Internet search (earlier: "selec-ted")	
ID	**Material**	**Authors (Year), Title, Publisher**	**Country & found via**	**Conclusion / preference**
AG-8	Recycled materials	**Hendriks, Ch. F., Janssen, G.M.T. and Vogtlander, J. (2003):** Assessment of recycled materials with the eco-costs/value ratio model. Recycling and Reuse of Waste Materials, Proceedings of the International Symposium and Recycling and Reuse of Waste Materials	DADS	
AG-9	Pavement binding courses	**Ventura, A.; Mazri, Ch.; Moneron, P.; Jullien, A.; Guidoux, Y. and Schemid, M. (2004):** Environmental comparison of pavement binding courses recycled at varying rates by means of the life cycle analysis method. Bulletin des Laboratoires des Ponts et Chaussees	DADS/ France	(in French)

AG-10	Minerals	**Plant, J.A.; Turner, R.K. and Highley, D.E. (1998):** Minerals and the environment. International Mining & Minerals	DADS/ Europe	
AG-11	Composites	**Anonymous (2003):** How Trent Concrete launched E&M Composites Quality Concrete	DADS	
AG-12	Concrete	**Osborne, G.J. (1999):** Durability of Portland blast-furnace slag cement concrete. Cement and Concrete Composites	DADS	
AG-13	Concrete	**Aitcin, P.-C. (2000):** Cements of yesterday and today - concrete of tomorrow. Cement and Concrete Research, 11 p.	DADS/ Canada	more life-long durable concrete needed
AG-14	Construction minerals	**McEvoy, D.; Ravetz, J. and Handley, J.:** Managing the flow of construction minerals in the north west region of England: A mass balance approach Journal of Industrial Ecology	DADS/UK	
AG-15	Asphalt and pavement materials	**Zapata, P. and Gambatese, J.A. (2005):** Energy consumption of asphalt and reinforced concrete pavement materials and construction. Sustainability of Transportation and Other Infrastructure Systems, Journal of Infrastructure Systems, vol.11, issue 1, pp. 9-20	DADS/ USA	EoL not included in calculations but recycling advantages described
AG-16	Sand-blasting sand (?)	**Dutch EPA (?) (2002):** Milieueffectrapport Landelijk Afvalbeheerplan (Environmental report, National Waste Treatment Plan)	Nether-lands, via experts	-
AG-17	Road construction materials/ designs	**Mroueh, U.-M.; Eskola, P. and Laine-Ylijoki, J. (2001):** Life-cycle impacts of the use of industrial by-products in road and earth construction. Waste Management (Journal), 21, p. 271-277	Finland, via Internet	Comparison of raw materials/ designs, high recycling content preferable
AG-18	Concrete products	**Vares, S. and Häkkinen, T.:** Environmental burdens of concrete and concrete products. Technical Research Centre of Finland. VTT Building Technology, 02044 VTT, http://www.itn.is/ncr/publications/doc-21-10.pdf	Finland, via Internet search	Cradle-to-grave profiles, EoL only qualitatively

ID	Material	Authors (Year), Title, Publisher	Country & found via	Conclusion/ preference
AG-19	Sewerage and drainage systems	**Dept. of Trade and Industry, DTI:** Environmental Assessment of UK Sewer Systems http://www.concretepipes.co.uk/CPAenvironment.pdf	UK, EU via Internet search	Concrete performs env. better than plastics in the application
AG-20	Bridge deck designs	**Kendall, A. (2004):** A Dynamic Life Cycle Assessment Tool for Comparing Bridge Deck Designs. University of Michigan, 87 pages http://css.snre.umich.edu/css_doc/CSS04-12.pdf	USA, via Internet search	Comparison of two designs
AG-21		**Howards, N., Edwards, S. and Anderson, J. (1999):** BRE methodology for environmental profiles of construction materials, components and buildings. http://cig.bre.co.uk/envprofiles/documentjsp?jsessionid:15831 1 1 1 151298444B4 66p. + 26p. addendum of 2000	UK/EU, via B. Thomas (Environ-ment Agency), from Internet	n.a.
AG-22		**van Santen, A., Poll, J., Thomas, T. and Bristow, L. (2005):** Analysis of fragmentiser residue. Report to the Environment Agency. AEAT/ENV/R/I846. www.environment-agency.gov.uk	UK, via B. Thomas (Environ-ment Agency), from Internet	n.a.
AG-23	Construction and demolition waste	**Eriksen, S.S.; Hansen, K. and Krogh, H. (2000):** Experience gained from the demolition of a housing block in Rødbyhavn (Denmark) Danish Building Research Institute (Statens ByggeforskningsInstitut, SBi) SBi meddelelse 120, 49 pages	Denmark, via targeted search, Tip of expert, (and SBI's homepage)	
AG-24	Recyclable materials incl. construction & demolition	**Anonymous (2000):** London remade - Developing markets for recyclable materials in London. Enviros RIS Ltd. 106 p.	UK, Internet search	n.a., useful statistics

General LCA references used in the review

Amato, A., Brimacombe, L. and Howard, N. (1996). Development of quantitative methodology for assessing embodied energy of recyclable and reusable materials/products. Ironmaking and Steelmaking, 1996, (23(3), 235-241).

APME (2004): Plastics in Europe, An analysis of plastics consumption and recovery in Europe, Published Summer 2004 http://www.apme.org

Arena, U., Mastellone, M. L. & Perugini F. (2003); The Environmental Performance of Alternative Solid Waste Management Options. A Life Cycle Assessment study. Chem. Eng. J., 96/1-3: 207-222 (2003)

Aumônier, S. and Coleman, T. (1997); Life cycle assessment for waste management planning. In: Proceedings Sardinia 97, Sixth International Landfill Symposium, 5, 155-164. CISA, Cagliary, Italy.

Baitz, Kreißig, Byrne, Makishi, Kupfer, Frees, Bey, S. Hansen, Hansen, Bosch, Borghi, Watson, Miranda (2004), Life Cycle Assessment of PVC and of principal competing materials, European Commiossion, http://europa.eu.int/comm/enterprise/chemicals/sustdev/pvc_en.htm

Barlaz, M.A.; Ranjithan, R; Weitz, K.A.; Nishtala, S.R.: Life-Cycle Study of Municipal Solid Waste Management – System Description (1995). USEPA Cooperative Agreement 832052, July 1995

Baumann, H., Ekvall, T., Eriksson, E., Kullman, M., Rydberg, T., Ryding, S.-O., Steen, B., and Svensson, G.

(1993); Miljömässiga skillnader mellan återvinning/återanvändning och förbränning/deponering, (Environmental differences between recycling/reuse and incineration/landfill). FoU nr 79, Stiftelsen Reforsk, Malmö, Sweden (In Swedish).
Björklund, A. and Finnveden, G. (2003); Recycling revisited - Comparing different waste management strategies. Presented at the 10th SETAC LCA Case Studies Symposium 3-4 December 2002, in Barcelona.
Björklund, a., Finnveden, J (2004) Recycling revisited. Life-cycle comparisons of waste management strategies. Accepted for publication in Resources, Conservation and recycling.
Björklund, A., Finnveden, J (2005) Recycling revisited. Life-cycle comparisons of waste management strategies. Accepted for publication in Resources, Conservation and recycling.
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Appendix 4. Material Systems and Their Boundaries

Paper material system

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

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

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

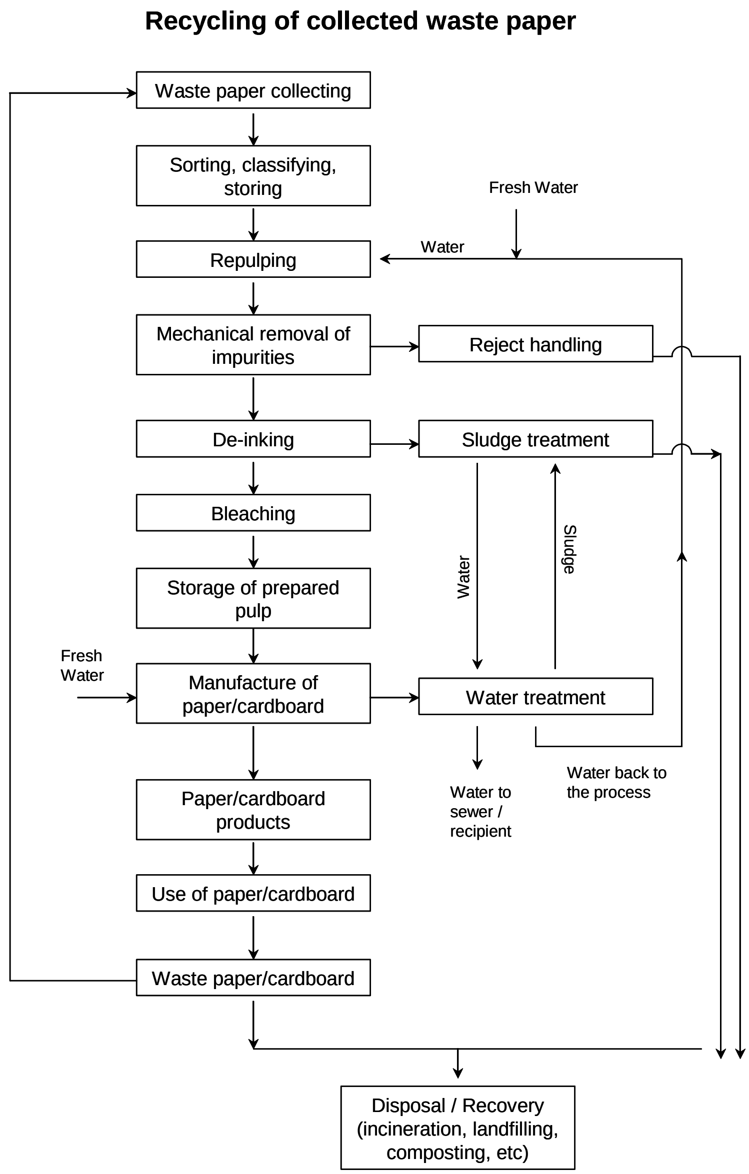


Figure A3.1 The manufacturing process of used paper

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 etc. 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 their 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 to 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 deinking

Ink removal is necessary in plants manufacturing paper grades where brightness is important e.g. for newsprint, printing and writing paper, tissue or light topliner of recovered paper based cardboards. The main objectives of deinking 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 deinking plant includes also the above mentioned basic unit operations repulping, screening and cleaning for removal of coarse contaminants (non-paper items as stones, sand, metal, string, glass, textiles, wood, plastic foils, paper clips etc.). Additionally to mechanical cleaning a chemical pretreatment of the pulp and a removal of printing inks in flotation cells is carried out. A prerequisite for successful deinking is that the ink particles are released from the fibres and kept in dispersion. For this purpose deinking chemicals as NaOH, soaps or fatty acids etc. 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. Deinking sludge is incinerated or landfilled.

After deinking 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 from hot-melt glues etc. These impurities can be dispersed so finely with a disperser that the particles are invisible to the naked eye.

Processes with wash deinking and ash removal

Flotation deinking is efficient for particle sizes from 5-100 µm. Smaller ink particles can be removed by wash deinking which is basically a multistage 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 deinking plant for preparation of collected waste paper to lightweight coated paper includes often both flotation and washing deinking 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 such as 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 reused in the process. The micro-flotation unit gives a sludge that is thickened and landfilled or incinerated. In case of washing deinking 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.

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 developments 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.

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 neither as raw material nor as fuel. In this case, the use of wood will take place at the expense of its marginal, which can be for eaxmple 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 for example Scandinavian countries in many cases from hydropower. The identification of the true marginal for these energy supplies is of utmost importance like also emphasized 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, give rise to excess energy that is exported to the societal grid. This should be accounted for properly, cf. 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 & 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, the 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

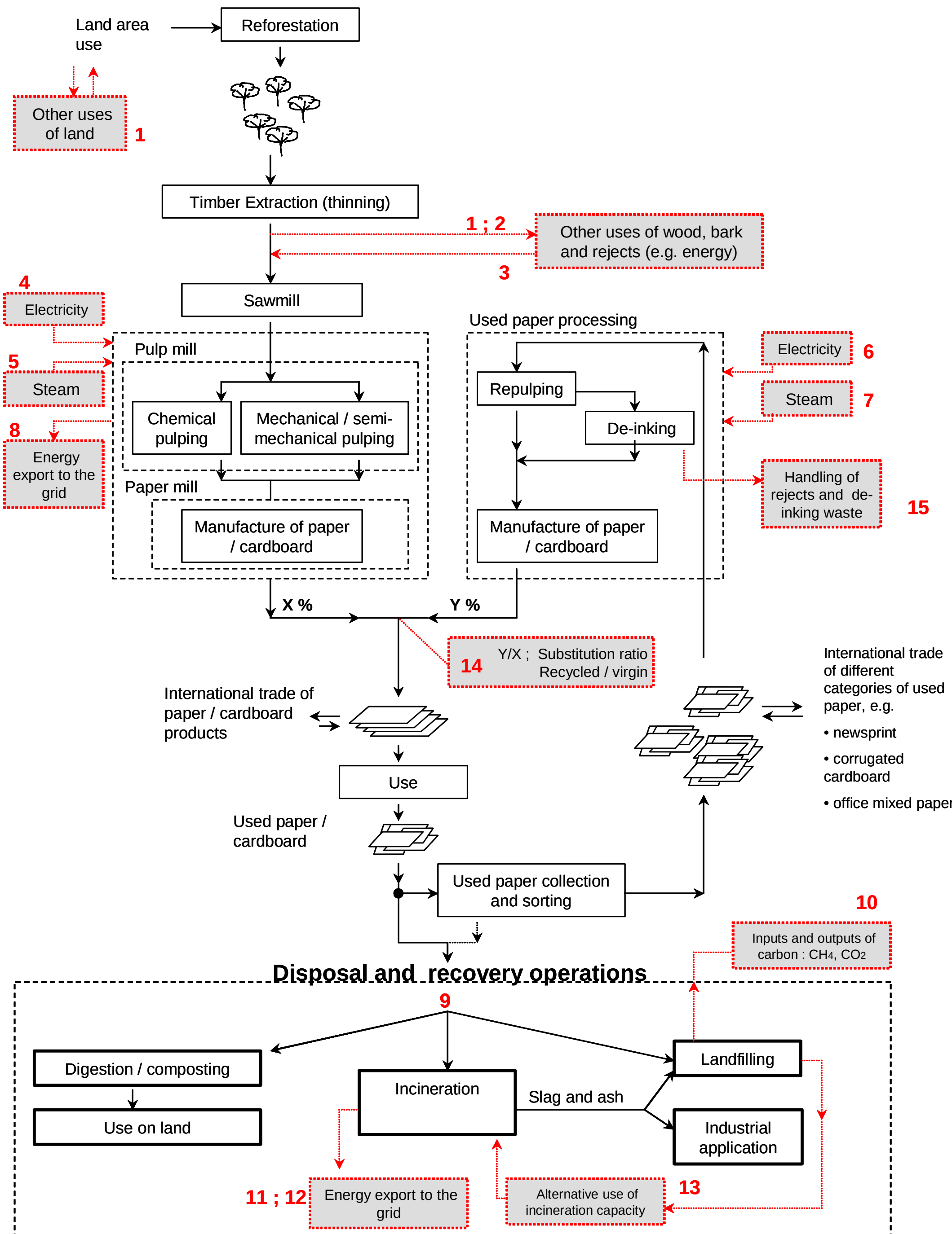
The anticipated disposal route or combination of disposal routes is important. But especially, it is important to clarify the increases and decreases in disposal routes when changes in the system occur. If for example an increase or decrease in recycling is studied, it should be clear if such increase/decrease is done at the expense of incineration, landfill or other disposal/recovery route, or to 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 used by incineration. In many incineration plants, this energy can be transformed into electricity and supplied to the grid, or supplied directly as heat via e.g. 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 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, some capacity of these facilities will be released. On the short term this may imply the use of e.g. 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 weight 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 6-7 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. Rather, a 1:0.8 ratio should be anticipated, 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.

The paper system



System boundary discussion for Glass, Plastics, Aluminium, Steel, Wood and Aggregates

Items 1-4: System boundary issues in the raw material and production stages
Primary (i.e. virgin) material production from raw materials can take place using different technologies and raw material quality with related emissions, and therefore it is important to define what exactly is the marginal virgin material. Some studies are not fully aware of this, and many use just an average of data for several works. Others use data for one specific works without this being the marginal on the market. Environmental impacts do, however, vary very much from one works to the other, and it is, therefore, essential to report which type of virgin material has been anticipated. This key issue is illustrated in position 1.

In the production of primary materials, the energy supply is in almost every case of fossil origin, both for electricity and fuel for the machines utilised. The production and transportation of materials is energy demanding, and so it is important to identify the true marginals for potential thermal energy and especially electricity. For example, some companies may have established their own heat & power co-generation plants. It is therefore important to identify the true marginals for steam and electricity in such cases. This key issue is indicated in positions 2 and 3 in Figure 3.3.

In addition, materials production gives rise to secondary products, rejects and other wastes, the handling of which may give rise to both environmental impacts and/or secondary services (co-products) that should be accounted for. This key issue is illustrated in position 4.

Items 5-8: System boundary issues in the recovered material production stages
As primary material production is frequently energy demanding, recycling is often undertaken using rejects and scrap post-production or post-consumer waste to reduce the energy input required. This may be the case in particular for aluminium, steel and glass. There is an issue of including the correct energy marginals.

The recovery pathways will depend on the material type, and can involve mechanical recovery and chemical processes carried out on-site (e.g. crushing or chipping) or off-site (e.g. re-melting) at dedicated recovery plants.

As the recovery pathways have different and potentially large environmental impacts (e.g. due to intensive machinery use and transport activity), it is imperative to state the recovery process in question. There is also an issue of whether average or site specific data is used for the recycled material stream.

These key issues are illustrated in positions 5 to 8 in Figure 3.3.

Items 9-10: System boundary issues in the ante-material recovery stage
Waste materials may be collected, sorted according to its quality, and processed in order to make it ready for recovery and recycling. These operations may be product-dependent or non-product dependent. The type of processing operation, its consumption of materials, energy (marginals) and emissions have to be specified in an LCA. This key issue is illustrated in positions 9 and 10 in Figure 3.3.

Items 11-15: 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, whether such increase/decrease is done at the expense of incineration, landfill or other disposal/recovery route, or to a mix of these. This key issue is depicted in position 11 in Figure 3.3.

Emissions from landfills tend to have a high significance in the overall contribution to global warming for biodegradable waste streams, due to the formation and release of methane. Although presumably less important regarding aluminium, potential leachate emissions might be of general interest. However, such emissions are seldom accounted for in LCAs. This general key issue is indicated in position 12 in Figure 3.3.

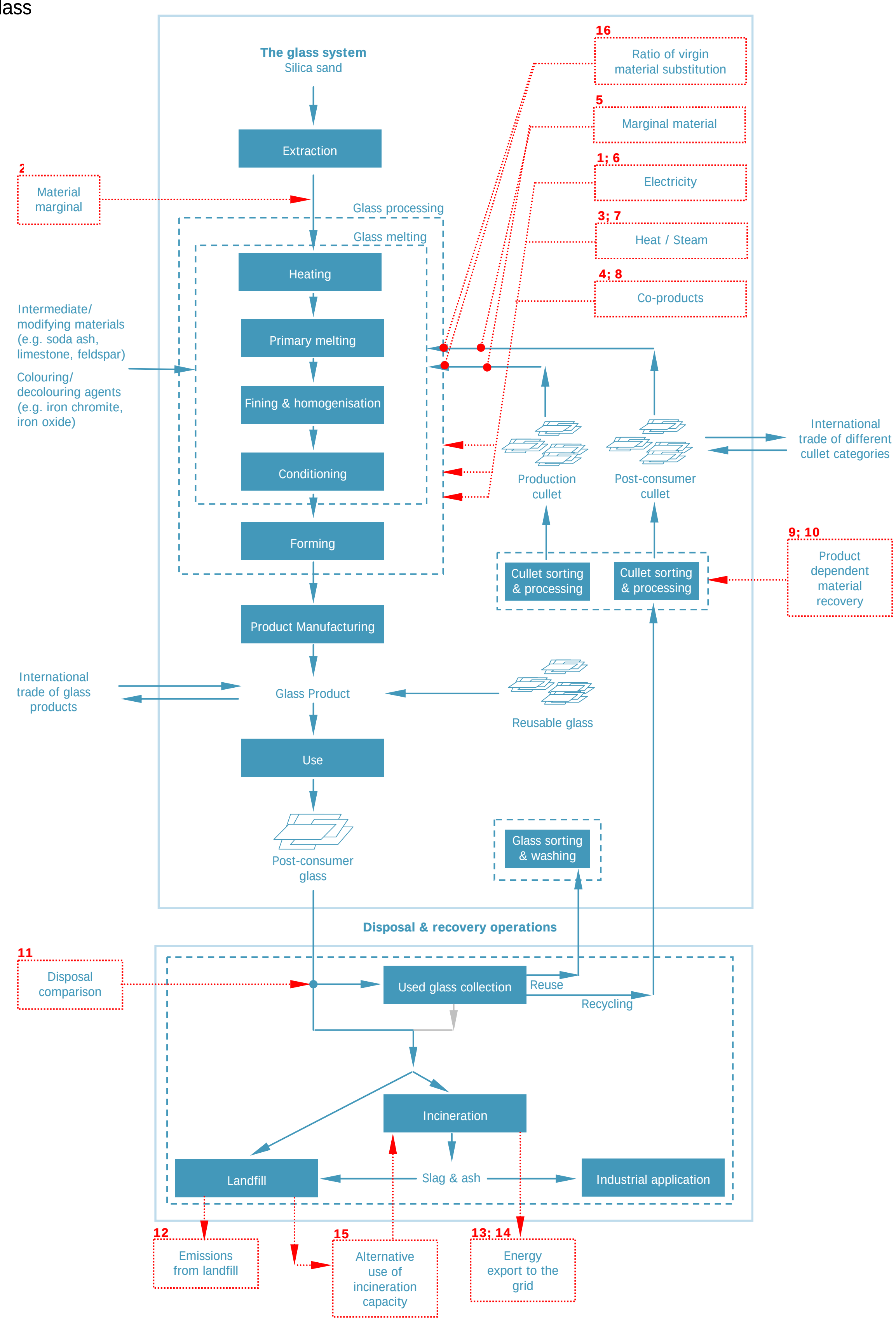
Many of the waste materials discussed have a positive calorific value, and this energy can be released and utilised via incineration. In many incineration plants, the energy can be transformed into electricity and supplied to the grid, or supplied directly as heat via e.g. district heating. Conversely, many materials do not combust. In LCAs, different assumptions are made to account for the potential energy recovery, and energy recovery is divided differently between electricity and heat production.

Moreover, electricity and heat from incineration plants substitute 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 13 and 14 in Figure 3.3. When specific material recycling is done at the expense of incineration/landfilling, the capacity of these facilities will be released. On the short term this may imply the use of e.g. 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 15 in Figure 3.3.

Item 16: Substitution and functionality
Finally, the materials reviewed can be easily recovered and the primary material substituted in many applications in a ratio up to 1:1. This is the case for aluminium, glass, steel and aggregates, but is not so with other recyclable materials such as wood, paper or plastic, where there is a quantifiable quality loss only replaceable by the continuous addition of virgin materials. For instance, any recycling of paper gives rise to a need for a certain amount of virgin paper input, being normally around 20%. In the case of aluminium, it is often, correctly, assumed that recycled material substitutes primary material by 100% (equivalent to ratio of 1:1), but this assumption should be clearly stated.

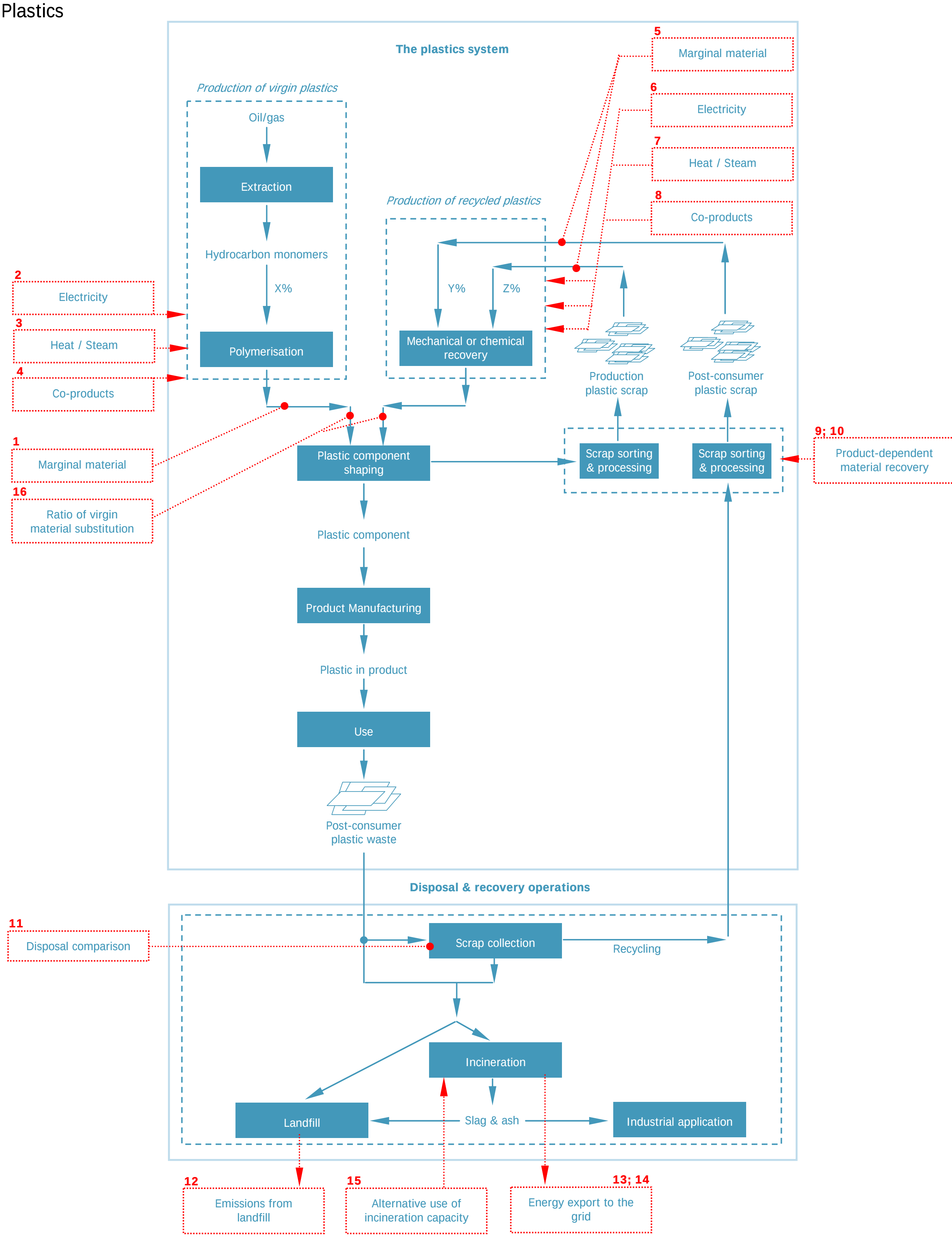
This key issue is indicated in position 16 in Figure 3.3, not meaning that the physical flow of virgin material occurs at this exact point, but just representing that the overall ratio of recycled material to virgin material can be illustrated in this point of Figure 3.3.

Glass

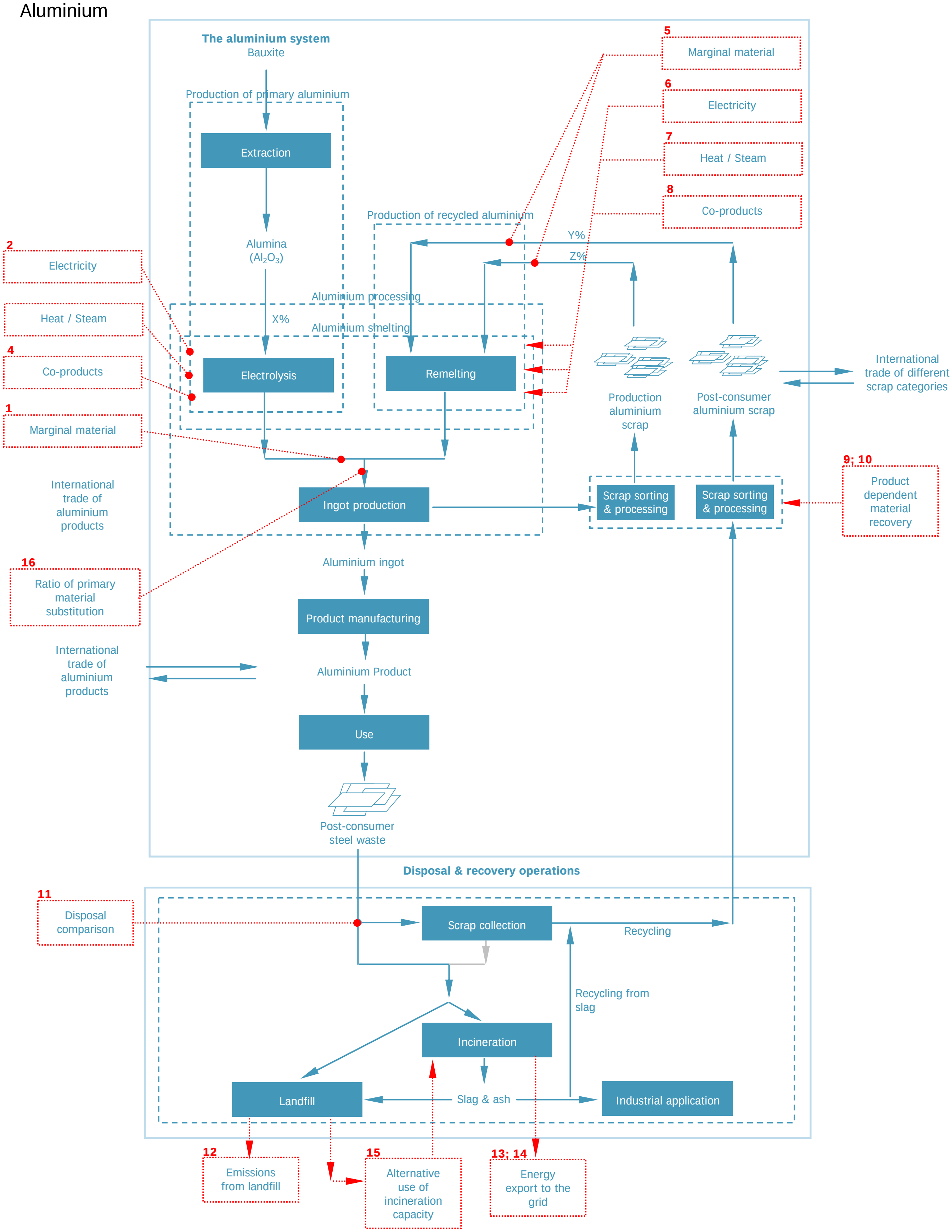


The glass system
Silica sand
Extraction
Material marginal
2
Glass processing
Glass melting
Heating
Primary melting
Fining & homogenisation
Conditioning
Forming
Intermediate/ modifying materials (e.g. soda ash, limestone, feldspar)
Colouring/ decolouring agents (e.g. iron chromite, iron oxide)
16
Ratio of virgin material substitution
5
Marginal material
1; 6
Electricity
3; 7
Heat / Steam
4; 8
Co-products
Production cullet
Post-consumer cullet
International trade of different cullet categories
Cullet sorting & processing
Cullet sorting & processing
9; 10
Product dependent material recovery
Product Manufacturing
International trade of glass products
Glass Product
Reusable glass
Use
Post-consumer glass
Glass sorting & washing
Disposal & recovery operations
11
Disposal comparison
Used glass collection
Reuse
Recycling
Incineration
Landfill
Slag & ash
Industrial application
12
Emissions from landfill
15
Alternative use of incineration capacity
13; 14
Energy export to the grid

Plastics

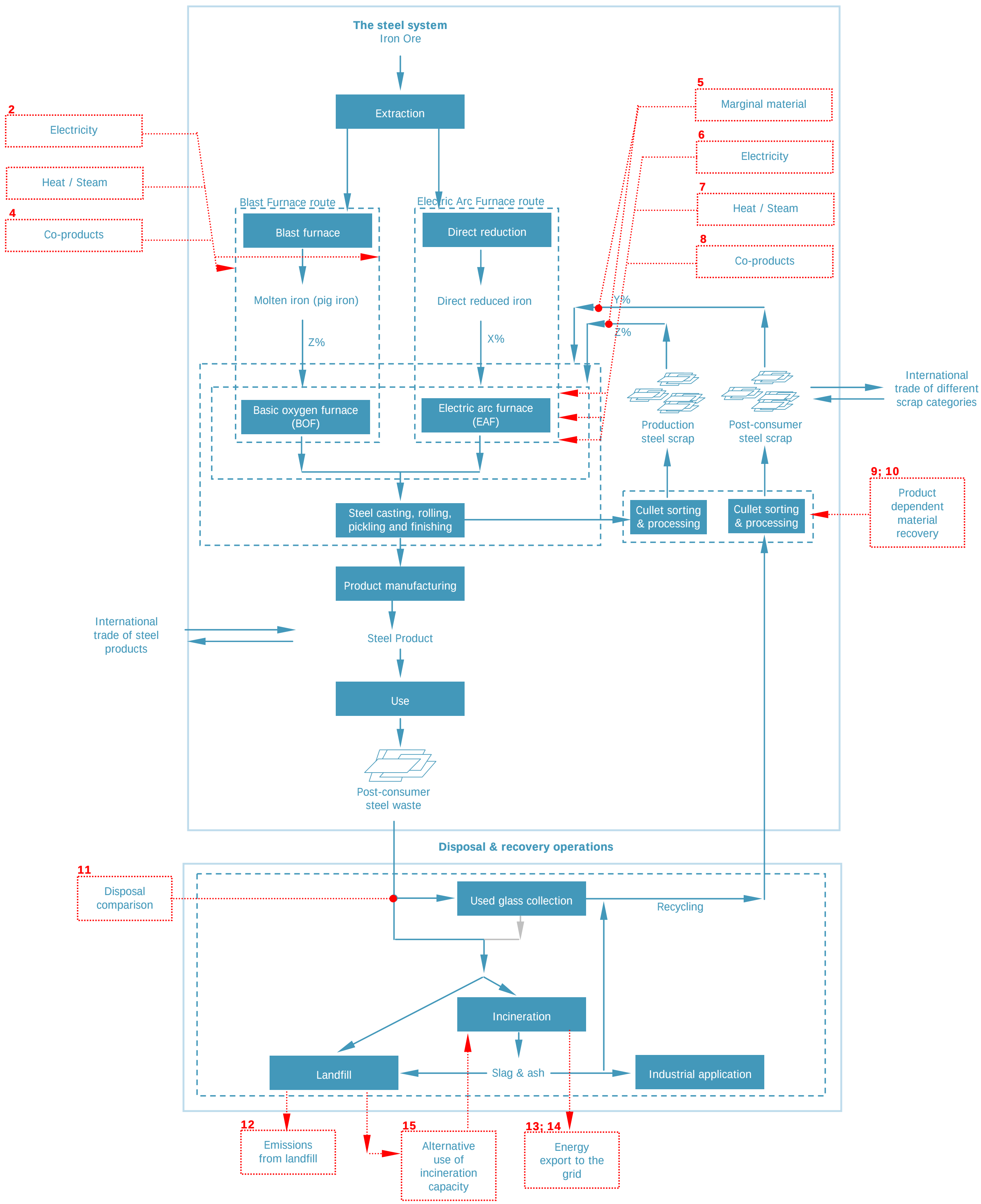

The plastics system
Production of virgin plastics
Oil/gas
Extraction
Hydrocarbon monomers
X%
Polymerisation
Production of recycled plastics
Y%
Z%
Mechanical or chemical recovery
Production plastic scrap
Post-consumer plastic scrap
5 Marginal material
6 Electricity
7 Heat / Steam
8 Co-products
2 Electricity
3 Heat / Steam
4 Co-products
1 Marginal material
16 Ratio of virgin material substitution
Plastic component shaping
Scrap sorting & processing
Scrap sorting & processing
9; 10 Product-dependent material recovery
Plastic component
Product Manufacturing
Plastic in product
Use
Post-consumer plastic waste
Disposal & recovery operations
11 Disposal comparison
Scrap collection
Recycling
Incineration
Landfill
Slag & ash
Industrial application
12 Emissions from landfill
15 Alternative use of incineration capacity
13; 14 Energy export to the grid

Aluminium



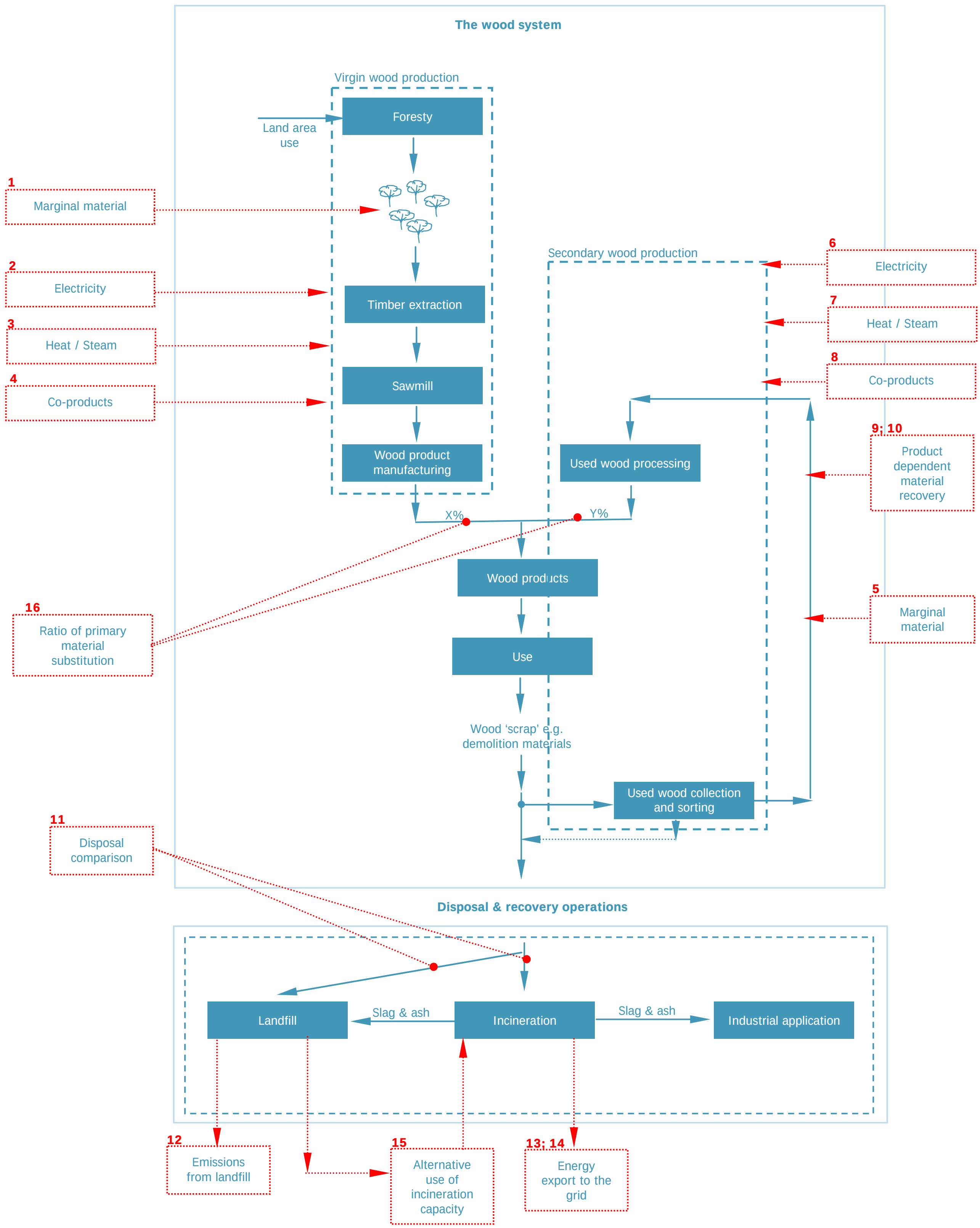
The aluminium system
Bauxite
Production of primary aluminium
Extraction
Alumina
(Al_2O_3)
X%
Production of recycled aluminium
Y%
Z%
Aluminium processing
Aluminium smelting
Electrolysis
Remelting
Ingot production
Aluminium ingot
Product manufacturing
Aluminium Product
Use
Post-consumer
steel waste
Production aluminium scrap
Post-consumer aluminium scrap
International trade of different scrap categories
Scrap sorting & processing
Scrap sorting & processing
International trade of aluminium products
International trade of aluminium products
1
Marginal material
2
Electricity
Heat / Steam
4
Co-products
5
Marginal material
6
Electricity
7
Heat / Steam
8
Co-products
9; 10
Product dependent material recovery
16
Ratio of primary material substitution
Disposal & recovery operations
11
Disposal comparison
Scrap collection
Recycling
Recycling from slag
Incineration
Landfill
Slag & ash
Industrial application
12
Emissions from landfill
15
Alternative use of incineration capacity
13; 14
Energy export to the grid

Steel



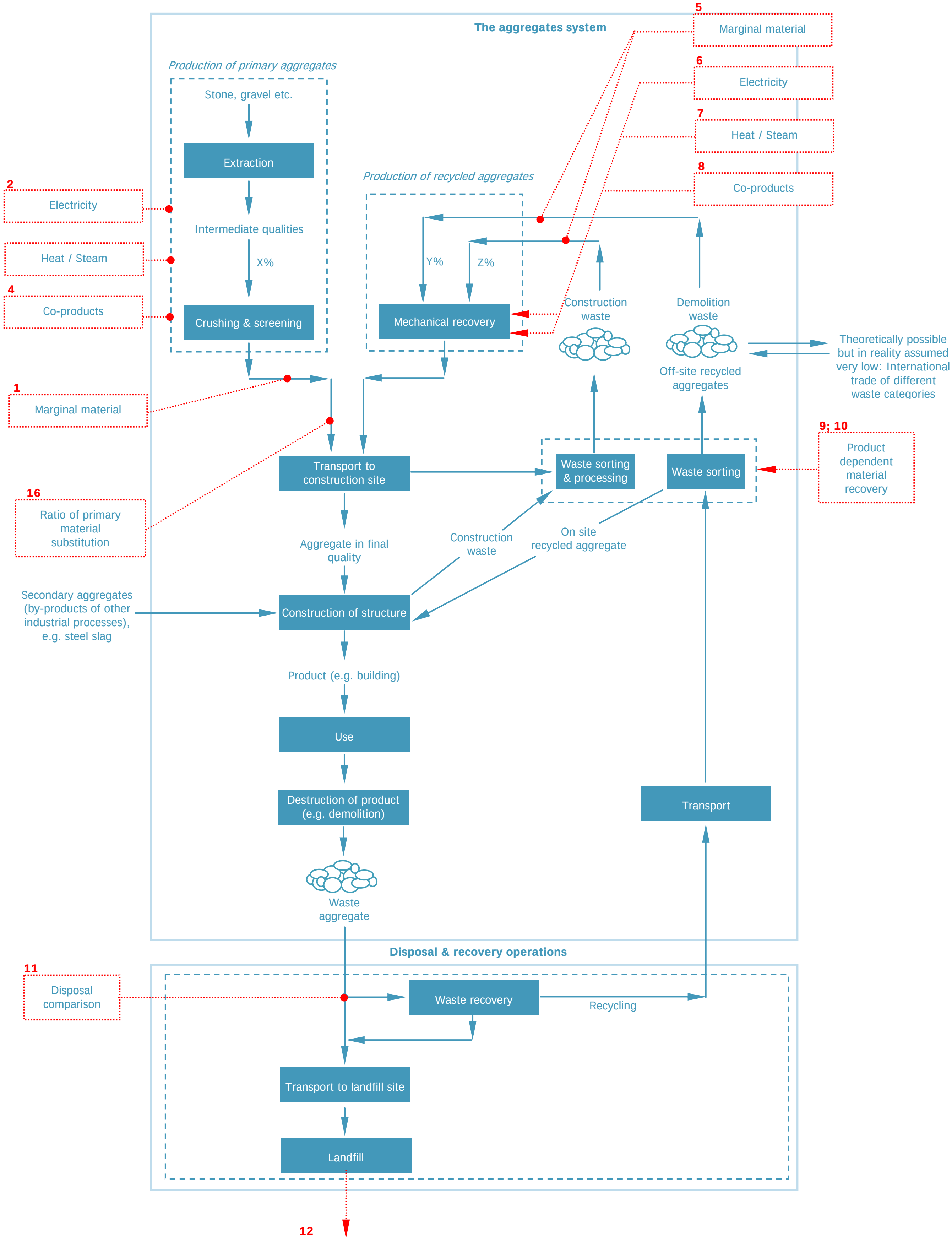
The steel system
Iron Ore
Extraction
2
Electricity
Heat / Steam
4
Co-products
5
Marginal material
6
Electricity
7
Heat / Steam
8
Co-products
Blast Furnace route
Blast furnace
Electric Arc Furnace route
Direct reduction
Molten iron (pig iron)
Direct reduced iron
Z%
X%
Y%
Z%
Basic oxygen furnace (BOF)
Electric arc furnace (EAF)
Production steel scrap
Post-consumer steel scrap
International trade of different scrap categories
9; 10
Product dependent material recovery
Steel casting, rolling, pickling and finishing
Cullet sorting & processing
Cullet sorting & processing
Product manufacturing
International trade of steel products
Steel Product
Use
Post-consumer steel waste
Disposal & recovery operations
11
Disposal comparison
Used glass collection
Recycling
Incineration
Landfill
Slag & ash
Industrial application
12
Emissions from landfill
15
Alternative use of incineration capacity
13; 14
Energy export to the grid

Wood



The wood system
Virgin wood production
Land area use
Foresty
Timber extraction
Sawmill
Wood product manufacturing
Secondary wood production
Used wood processing
X%
Y%
Wood products
Use
Wood 'scrap' e.g. demolition materials
Used wood collection and sorting
1
Marginal material
2
Electricity
3
Heat / Steam
4
Co-products
6
Electricity
7
Heat / Steam
8
Co-products
9; 10
Product dependent material recovery
5
Marginal material
16
Ratio of primary material substitution
11
Disposal comparison
Disposal & recovery operations
Landfill
Slag & ash
Incineration
Slag & ash
Industrial application
12
Emissions from landfill
15
Alternative use of incineration capacity
13; 14
Energy export to the grid

Aggregates



The aggregates system
Production of primary aggregates
Stone, gravel etc.
Extraction
Intermediate qualities
X%
Crushing & screening
Production of recycled aggregates
Y%
Z%
Mechanical recovery
Construction waste
Demolition waste
Off-site recycled aggregates
Theoretically possible but in reality assumed very low: International trade of different waste categories
5
Marginal material
6
Electricity
7
Heat / Steam
8
Co-products
2
Electricity
Heat / Steam
4
Co-products
1
Marginal material
16
Ratio of primary material substitution
9; 10
Product dependent material recovery
Transport to construction site
Waste sorting & processing
Waste sorting
Aggregate in final quality
Construction waste
On site recycled aggregate
Secondary aggregates (by-products of other industrial processes), e.g. steel slag
Construction of structure
Product (e.g. building)
Use
Destruction of product (e.g. demolition)
Waste aggregate
Transport
Disposal & recovery operations
11
Disposal comparison
Waste recovery
Recycling
Transport to landfill site
Landfill
12

Appendix 5. Summary matrices for analysed LCA studies

Study	**S1 -** Tillman et al. (1991)
Study conductor/ commissioner	Conductor: Chalmers Industriteknik, CIT Commissioner: Statens Offentliga Utredningar, Miljödepartementet
Covered region	Sweden
Study characterisation	Characterise the environmental profile of the life cycle of different products, incl. Corrugated board and paper board for packaging liquids Life cycle of 1kg of corrugated board and of 1kg of paper board for packaging liquids

Scenarios			Recycling (80%) + landfilling (20%) - vs. landfill (100%)	Recycling (80%) + incineration (20%) - vs. incineration (100%)	Recycling (65%) + landfilling (35%) - vs. landfill (100%)	Recycling (65%) + incineration (35%) - vs. incineration (100%)
Scenario no.			1.1	1.2	1.3	1.4
Paper type			Corrugated board	Corrugated board	Paper board	Paper board
System boundaries						
Raw materials / forestry	1	Alternative use of land/wood included?	No inf.	No inf.	No inf.	No inf.
	2	Saved wood used for energy?	no	no	no	no
	3	Wood marginal	No inf.	No inf.	No inf.	No inf.
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	No inf.	No inf.	No inf.	No inf.
	6	Recovered paper - Electricity marginal	Fossil.	Fossil.	Fossil.	Fossil.
	7	- Steam marginal	No inf.	No inf.	No inf.	No inf.
	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?	No inf.	No inf.	No inf.	No inf.
	12	Energy from incineration substitutes electricity?	No inf.	No inf.	No inf.	No inf.
	13	Alternative use of incineration capacity incl.?	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)	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8
	15	De-inking sludge considered?	no	no	no	no
Impact Assessment: Relative difference: (recycling-alternative option)/alternative option						
Energy			- 64 %	- 46 %	- 43 %	- 22 %
Resource consumption		Fossil fuels	No inf.	No inf.	No inf.	No inf.
		Others	No inf.	No inf.	No inf.	No inf.
Global warming **			- 30 %	+ 100 %	- 31 %	+ 90 %
CO_2 saving (ton CO_2-eq./ton paper)			- 0.1	+ 1.0	- 0.2	+ 0.3
Other energy-related impacts *			- 50 %	+ 50 %	- 10 %	+ 50 %
Toxicity			No inf.	No inf.	No inf.	No inf.
Waste			- 79 %	+ 33 %	- 52 %	+ 1260 %
Other (e.g. biodiversity, wastewater impacts)			Wastewater: COD: + 33 %	Wastewater: COD: + 33 %	Wastewater: COD: - 19 %	Wastewater: COD: - 19 %

NOTES:
* Acidification, nutrient enrichment, and photochemical ozone creation, POCP. CH_4 from landfills not included in POCP
** Note that CH_4 emissions from landfills are not included in global warming.

Study	**S2 -** Dalager et al., (1995)
Study conductor/ commissioner	Conductor: dk-TEKNIK, Danish Technological Institute, Econet, National Environmental Research Institute Commissioner: Danish Environmental Protection Agency
Covered region	Denmark
Study characterisation	Evaluate the environmental performance of increased paper recycling Recovery/disposal under different scenarios of the Danish production of used paper, 1995 End-of-line comparison – whole life cycle not included.

Scenario			Recycling vs. incineration – excl. use of saved wood	Recycling vs. landfilling – excl. use of saved wood	Recycling versus incineration – incl. use of saved wood	Recycling versus landfilling – incl. use of saved wood
Scenario no.			2.1	2.2	2.3	2.4
Paper type			Corrugated cardboard	Corrugated cardboard	Corrugated cardboard	Corrugated cardboard
System boundaries						
Raw mat./ forestry	1	Alternative use of land/wood included?	no	no	yes	yes
	2	Saved wood used for energy?	no	no	yes	yes
	3	Wood marginal	wood	wood	wood	wood
Paper production		Virgin paper				
	4	Electricity marginal	fossil	fossil	fossil	fossil
	5	Steam marginal	wood	wood	wood	wood
		Recovered paper				
	6	Electricity marginal	fossil	fossil	fossil	fossil
	7	Steam marginal	fossil/straw	fossil/straw	fossil/straw	fossil/straw
	8	Energy export from virgin paper included?	no	no	no	no
Disposal	9	Main alternative to recycling	Incineration	Landfilling	Incineration	Landfilling
	10	Emissions from landfill included?	yes	yes	yes	yes
	11	Energy from incineration substitutes heat?	yes	yes	yes	yes
	12	Energy from incineration substitutes electricity?	no	no	no	no
	13	Alternative use of incin-eration capacity incl.?	no	yes	no	yes
	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
	15	De-inking sludge included?	yes	yes	yes	yes
Impact Assessment: recycling vs. alternative option: less = less impact from recycling, more = more impact from recycling						
Energy			Less	Less	Less	Less
Resource consumption (fossil fuels)			More	More	Less	Less
Global warming			More	Less	Less	Less
CO_2 saving (ton CO_2-eq./ton paper)			+ 1.1	- 2.8	- 0.9	- 4.6
Other energy-related impacts *		SO_2	More	More	Less	Less
		NO_x	Less	More	Less	More
Toxicity			No inf.	No inf.	No inf.	No inf.
Waste			Unchanged	Less	No inf.	No inf.
Other (wastewater impacts)			Less	Less	Less	Less

NOTES:

* Acidification, nutrient enrichment, and photochemical ozone creation, POCP

Scenario			Recycling vs. incineration – excl. use of saved wood	Recycling vs. a mix of incineration and landfilling – excl. use of saved wood	Recycling vs. incineration – incl. use of saved wood	Recycling vs. a mix of incineration and landfilling – incl. use of saved wood
Scenario no.			2.5	2.6	2.7	2.8
Paper type			Newsp. & magazines	Newsp. & magazines	Newsp. & magazines	Newsp. & magazines
System boundaries						
Raw mat./ forestry	1	Alternative use of land/wood included?	no	no	yes	yes
	2	Saved wood used for energy?	no	no	yes	yes
	3	Wood marginal	wood	wood	wood	wood
Paper production	4	Virgin paper Electricity marginal	fossil	fossil	fossil	fossil
	5	Steam marginal	wood	wood	wood	wood
	6	Recovered paper Electricity marginal	fossil	fossil	fossil	fossil
	7	Steam marginal	fossil	fossil	fossil	fossil
	8	Energy export from virgin paper included?	no	no	no	no
Disposal	9	Main alternative to recycling	Incineration	Incineration and landfilling (65/35)	Incineration	Incineration and landfilling (65/35)
	10	Emissions from landfill included?	yes	yes	yes	yes
	11	Energy from incineration substitutes heat?	yes	yes	yes	yes
	12	Energy from incineration substitutes electricity?	no	no	no	no
	13	Alternative use of incin-eration capacity incl.?	no	yes	no	yes
	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
	15	Disposal of de-inking sludge included?	yes	yes	yes	yes
Impact Assessment: recycling vs. alternative option: less = less impact from recycling, more = more impact from recycling						
Energy			Less	Less	Less	Less
Resource consumption			Less	Less	Less	Less
Global warming			Less	Less	Less	Less
CO_2 saving (ton CO_2-eq./ton paper)			- 1.7	- 4.7	- 3.4	- 6.5
Other energy-related impacts *			Less	Less	Less	Less
Toxicity			No inf.	No inf.	No inf.	No inf.
Waste			Less	Less	No inf.	No inf.
Other (wastewater impacts)			Less	Less	Less	Less

NOTES:
* Acidification, nutrient enrichment, and photochemical ozone creation, POCP

Scenario			Recycling vs. incineration – excl. use of saved wood	Recycling vs. a mix of incineration and landfilling (≈ 50/50) – excl. use of saved wood	Recycling vs. incineration – incl. use of saved wood	Recycling vs. a mix of incineration and landfilling (≈ 50/50) – incl. use of saved wood
Scenario no.			2.9	2.10	2.11	2.12
Paper type			Mixed paper	Mixed paper	Mixed paper	Mixed paper
System boundaries						
Raw mat./ forestry	1	Alternative use of land/wood included?	no	no	yes	yes
	2	Saved wood used for energy?	no	no	yes	yes
	3	Wood marginal	wood	wood	wood	wood

Paper production	Virgin paper					
	4	Electricity marginal	fossil	fossil	fossil	fossil
	5	Steam marginal	wood	wood	wood	wood
	Recovered paper					
	6	Electricity marginal	fossil	fossil	fossil	fossil
	7	Steam marginal	fossil	fossil	fossil	fossil
	8	Energy export from virgin paper included?	no	no	no	no
Disposal	9	Main alternative to recycling	Incineration	Incineration/Landfilling (≈ 50/50)	Incineration	Incineration/Landfilling (≈ 50/50)
	10	Emissions from landfill included?	yes	yes	yes	yes
	11	Energy from incineration substitutes heat?	yes	yes	yes	yes
	12	Energy from incineration substitutes electricity?	no	no	no	no
	13	Alternative use of incineration capacity incl.?	no	yes	no	yes
	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
	15	Disposal of de-inking sludge included?	yes	yes	yes	yes
Impact Assessment: recycling vs. alternative option: less = less impact from recycling, more = more impact from recycling						
Energy			Less	Less	Less	Less
Resource consumption			More	More	Less	Less
Global warming			More	Less	Less	Less
CO_2 saving (ton CO_2-eq./ton paper)			+ 0.7	- 2.3	- 1.5	- 4.5
Other energy-related impacts *			Unchanged	Less	Less	Less
Toxicity			No inf.	No inf.	No inf.	No inf.
Waste			Unchanged	Less	No inf.	No inf.
Other (wasterwater impacts)			Less	Less	Less	Less

NOTES:
* Acidification, nutrient enrichment, and photochemical ozone creation, POCP

Study	**S3 -** Virtanen and Nilsson, 1993
Study conductor/ commissioner	Conductor: IIASA, International Institute for Applied Systems Analysis Commissioner: No inf.
Covered region	Austria Finland, France, Italy, the Netherlands, Sweden, United Kingdom and Western Germany
Study characterisation	Decision to support: comparison of total incineration vs. maximum recycling

		Scenarios	Maximum recycling vs. Maximum incineration
		Scenario no.	3.1
		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?	No inf.
	2	Saved wood used for energy?	No inf.
	3	Wood marginal	No inf.
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?	No inf.
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)	No inf.
	15	De-inking sludge considered?	No
		Impact Assessment: Relative difference: (recycling-incineration)/incineration	
		Energy	- 25 %
Resource consumption		Fossil fuels	+ 75 %
		Renewable fuels and auxiliary chemicals	- 60 %
		Global warming	CO_2: + 150 % CH_4: - 50 % ** CO_2-eq.: -30 % **
		CO_2 saving (ton CO_2-eq./ton paper)	-2.5 kg CO_2-eq/kg (CO_2: + 1.2 kg CO_2-eq./kg) (CH_4: - 0.15 kg/kg = -0.15 * 25 = -3.75 kg CO_2-eq./kg)
		Other energy-related impacts *	-25 % to - 50 %
		Toxicity	No inf.
		Waste	
		Other (e.g. biodiversity, wastewater impacts)	Wastewater: BOD: 0% COD: - 40 % AOX: - 70 %

NOTES

* acidification, nutrient enrichment, tropospheric ozone formation. Any CH4 from anaerobic biodegradation also included

** methane formation from waste wood from forestry (harvesting waste), the quantity of which dominates the global warming contrbution

Other relevant assumptions:

- Equal composition of waste paper in the different countries
- Emission inventories are incomplete
- Only simplified sensitivity analysis

Study	**S4-** Kärnä et al. (1995) & Kärnä et al. (1994)
Study conductor/ commissioner	Conductor: The Finnish Pulp and Paper Institute, KCL Commissioner: No inf. – KCL owned by major Finnish paper industry
Covered region	Germany, Finland
Study characterisation	Paper reuse vs. paper incineration to reduce landfilling 1000 kg paper/yr delivered to consumers in Germany, 1990. Virgin paper imported from Finland

Scenarios			Recycling vs. incineration, with a high collection rate (60%)	Recycling vs. incineration, with a high collection rate (52%)
Scenario no.			4.1	4.2
Paper /cardboard type			newsprint	magazines
System boundaries				
Raw materials / forestry	1	Alternative use of land/wood included?	No inf.	No inf.
	2	Saved wood used for energy?	No inf.	No inf.
	3	Wood marginal	No inf.	No inf.
Paper production	4	Virgin paper - Electricity marginal	Wood/ Average electricity in Finland (**)	Wood/ Average electricity in Finland (**)
	5	- Steam marginal	wood	wood
	6	Recovered paper - Electricity marginal	Average in Germany (**)	Average in Germany (**)
	7	- Steam marginal	No inf.	No inf.
	8	Energy export from virgin paper included?	No inf.	No inf.
Disposal	9	Main alternative to recycling	Incineration (***)	Incineration (***)
	10	Emissions from landfill included?	Yes. 1/3 of potential	Yes. 1/3 of potential
	11	Energy from incineration substitutes heat?	no	No
	12	Energy from incineration substitutes electricity?	Yes, 33% efficiency	Yes, 33% efficiency
	13	Alternative use of incineration capacity incl.?	No inf.	No inf.
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	1(***)	1(***)
	15	De-inking sludge considered?	Yes	yes
Impact Assessment: Relative difference: (recycling-incineration)/incineration				
Energy			- 45 %	- 10 %
Resource consumption	Fossil fuels		+ 30 % (would be -15 % if fossil marginal electricity were used) **	+ 5 %
	Others		No inf.	No inf.
Global warming			+ 63 % (would be -15 % if fossil marginal electricity were used)	+ 5 %
CO_2 saving (ton CO_2-eq./ton paper)			+ 1.0	+ 0.75
Other energy-related impacts *			SO_2: + 50 % ** NOx: 0 % ** VOC: -5 % **	SO_2: 0 % NOx: 0 % VOC: 0 %
Toxicity			No inf.	No inf.
Waste				
Other (e.g. biodiversity, wastewater impacts) Wastewater			Wastewater: COD: 0 % AOX: + 50 %	Wastewater: COD: 0 % AOX: -15 %

NOTES:
No information is given on the weighting factors used and the background of the interpretation of results
* acidification, nutrient enrichment, tropospheric ozone formation. Any CH4 from anaerobic biodegradation also included
** Average energy generation in Finland, 1990, but no marginal study. Average energy generation in Germany, 1990, but no marginal study. Results for resource consumption of fossil fuels, global warming and other energy related impacts would revert (show advantage for recycling) if a fossil marginal electricity were used.
*** The mass balance of the recycling of paper is not described. Feeding and Sinks of the system missing. Data presumably show results per 1000 kg with a difference of 600 kg being either recycled or incinerated with energy recovery

Study	**S5** - Ecobalance UK, (1998)
Study conductor/ commissioner	Conductor: Ecobilan Group (Ecobalance UK) Commissioner: the company Aylesford Newsprint Ltd. (ANL)
Covered region	United Kingdom
Study characterisation	Paper reuse in UK vs. paper incineration in UK and recycling in other countries (the study adopts the perspective of the recycling company Aylesford, UK). Disposal of 1000 kg used newspapers and magazines. End-of-line comparison – whole life cycle not included.

Scenarios			Recycling of newspapers and magazines at Aylesford, UK versus incineration with energy recovery and electricity supply to the UK national grid
Scenario no.			5.1
Paper /cardboard type			newsprint
System boundaries			
Raw materials / Forestry	1	Alternative use of land/wood included?	No inf.
	2	Saved wood used for energy?	No inf.
	3	Wood marginal	Wood. Presumably from ANL distribution countries (**)
Paper production	4	Virgin paper - Electricity marginal	Wood (data from Sweden)
	5	- Steam marginal	Wood (data from Sweden)
	6	Recovered paper - Electricity marginal	Grid: UK / the country of origin of waste paper (**) No consideration of marginal included.
	7	- Steam marginal	No inf.
	8	Energy export from virgin paper included?	No inf.
Disposal	9	Main alternative to recycling	Incineration in UK and recycling in other countries (***)
	10	Emissions from landfill included?	No
	11	Energy from incineration substitutes heat?	No inf.
	12	Energy from incineration substitutes electricity?	Yes. 25% efficiency
	13	Alternative use of incineration capacity incl.?	no (***)
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	Recycled paper substitutes 'a combination of virgin paper and other recycled paper'. Ratio not specified.
	15	De-inking waste included?	Yes (incinerated)
Impact Assessment: Relative difference: (recycling-incineration)/incineration ****			
Energy			-35 % ****
Resource consumption	Fossil fuels		+ 30 % ****
	Others		
Global warming			-15 % ****
CO_2 saving (ton CO_2-eq./ton paper)			-0.26
Other energy-related impacts *			-45 % ****
Toxicity			No inf.
Waste			No inf.
Other (e.g. biodiversity, wastewater impacts)			Wastewater: -60 %

NOTES:
ISO 14040 series is followed
* acidification, nutrient enrichment, tropospheric ozone formation
** 11 countries in line with current UK consumption, including Sweden, Norway, Finland, USA, Canada, Germany, Netherlands, France, Belgium, Spain, Russia.
*** no indication in the reference scenario (with no incineration in the UK) of what is the alternative to recycling in the other countries (landfill or incineration?)
**** Relative difference between end-of-life phase only – not the whole life cycle of the paper
No sensitivity analysis carried out!

Study	**S6-** Grant et al. (2001) LCA of paper and packaging waste management scenarios in Victoria
Study conductor/ commissioner	Conductor: CRC for Waste Management and Pollution Control, Centre for Waste and Water Technology at UNSW, National Centre for Design at RMIT, Centre for Packaging, Transportation and Storage at VUT acting on behalf of the Food and Packaging CRC. Commissioner: EcoRecycle Victoria
Covered region	Australia
Study characterisation	Evaluate the environmental performance of paper recycling vs. landfilling (no scenario with incineration). Management of the recyclable fraction of newsprint paper & board packaging from the average Melbourne household in one week (ca. 3.64 kg on average). End-of-line comparison – whole life cycle not included.

Scenarios			Recycling vs. landfill - Full degradation of carbon to CH_4 and CO_2	Recycling vs. landfill - 22% degradation of carbon to CH_4 and CO_2	Recycling vs. landfill - Full degradation of carbon to CH_4 and CO_2	Recycling vs. landfill - 47% degradation of carbon to CH_4 and CO_2
Scenario no.			6.1	6.2	6.3	6.4
Paper /cardboard type			newsprint	newsprint	cardboard packaging	cardboard 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	Wood	Wood	Wood	Wood
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?	No inf.	No inf.	No inf.	No inf.
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)	No inf. Presumably 1:1	No inf. Presumably 1:1	No inf. Presumably 1:1	No inf. Presumably 1:1
	15	De-inking sludge included?	yes	yes	yes	yes
Impact Assessment: difference: recycling-incineration **						
Energy			-0.41 MJ/kg	-4.4 MJ/kg	-0.60 MJ/kg	-2.16 MJ/kg
Resource consumption		Fossil fuels	No inf.	No inf.	No inf.	No inf.
		Others	Water: - 14 litres/kg	Water: -16 litres/kg	Water: - 12 litres/kg	Water: - 12 litres/kg
Global warming			-1.0 kg CO_2-eq./kg	+ 0.11 kg CO_2-eq./kg	-0.7 kg CO_2-eq./kg	-0.22 kg CO_2-eq./kg
CO_2 saving (ton CO_2-eq./ton paper)			-1.0	+ 0.11	-0.7	-0.22
Other energy-related impacts *			-0.02 g C_2H_4-eq./kg	-0.03 g C_2H_4-eq./kg	-0.02 g C_2H_4-eq./kg	-0.02 g C_2H_4-eq./kg
Toxicity			No inf.	No inf.	No inf.	No inf.
Waste			- 0.56 kg/kg	-0.60 kg/kg	-0.38 kg/kg	-0.40 kg/kg
Other (e.g. biodiversity, wastewater impacts)			No inf.	No inf.	No inf.	No inf.

NOTES:
* tropospheric ozone formation. CH4 from anaerobic biodegradation also included
** the relative difference over the whole life cycle cannot be calculated as the study is an end-of-life comparison only. The relative end-of-life difference cannot be calculated either, as many of the figures for one of the compared scenarios are negative.

several different allocation methods have been used
reviewed by CML, Netherlands

Study	**S7 -** Tiedemann et al. (2001)Environmental comparison of recycling and disposal processes of used graphic paper and newsprint
Study conductor/ commissioner	Conductor: Federal Environmental Agency of Germany (Umwelt Bundesamt Deutschland) Commissioner: Federal Environmental Agency of Germany (Umwelt Bundesamt Deutschland)
Covered region	Germany
Study characterisation	Identification of the disposal option(s) with lower environmental impacts. Studies the total production and processing of paper in Germany in 1995.

		Scenario	Recycling ** - increase from 69% to 76%	Recycling ** - decrease from 69% to 57%	Incineration in WIP ** - increase from 9% to 17%	Recycling - decrease from 69% to 57%	Recycling - increase from 57% to 76%	Recycling *** – decrease from 69% to 57%
		Scenario no.	7.1	7.2	7.3	7.4	7.5	7.6
		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	Wood	Wood	Wood	Wood	Wood	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?	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
Disposal	9	Alternative waste management option	30/70 WIP/landfill	30/70 WIP/landfill	Landfilling	Incineration in WIP	Incineration in CHP	Incineration in WIP
	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 incl.?	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?	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
		Impact Assessment: Relative difference: (scenario option-alt. option)/alt. option (alternative option as indicated in row 9 for each column)						
		Energy	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
		Resource consumption (fossil fuels) (est. difference per 100% option) **	-5 % (-50 to -75%)	-5 % (-50 to -75%)	-2 % (-0 to -25%)	-2 % (-0 to -25%)	-1 % (-0 to -25%)	-5 % (-50 to -75%)
		Global warming (est. difference per 100% option) **	-12 % (-75 to -100%)	-15 % (-75 to -100%)	-17 % (-50 to -75%)	+ 1.5 % (0 to 25%)	-1 % (-0 to -25%)	-5 % (-50 to -75%)
		CO_2 saving (ton CO_2-eq./ton paper)	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
		Other energy related impacts * (est. difference per 100% option) **	-3 % (-25 to -50%)	-3 % (-25 to -50%)	-4 % (-25 to -50%)	+ 2 % (0 to 25%)	0 % (0 %)	0 % (0 %)
		Toxicity (est. difference per 100% option) **	-1 % to -10 % (-25 to -50%)	-1 % to -10 % (-25 to -50%)	-1 % to -10 % (-25 to -50%)	0 % (0 %)	0 % (0 %)	0 % (0 %)
		Waste	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
		Other (ground level POCP/land use) (est. difference per 100% option) **	-23 %/-3 to -8% (-75 to -100%)/ (-25 to -50%)	-28 %/-6 to -15% (-75 to -100%)/ (-50 to -75%)	-28 %/No inf. (-75 to -100%)	0 %/-5 to -10% (0%)/ (-50 to -75%)	-9 %/-8 to -25% (-25 to -50%)/ (-50 to -75%)	-1 %/0% (-0 to -25%)/ (0 %)

NOTES: * acidification, nutrient enrichment, photochemical ozone creation (POCP). CH4 from anaerobic biodegradation also included in POCP, ** the reference does not contain data allowing to express results comparing disposal option to each other on a 100% basis. For e.g. scenario 7.1, results compare two alternative scenarios with a mix of disposal options including an *increase* in recycling of 7%. From these results, an extrapolation to 100% comparisons is *roughly estimated*. *** This scenario has been constructed from scenario 7.4 combined with a scenario showing the consequence of using saved wood (from recycling) fro CHP. WIP = Waste Incineration plants (with energy revovery), CHP = Co-generation Heat and Power plants

Study	**S8 -** Environmental Defense & Duke University (2002)
Study conductor/ commissioner	Conductor: The Paper Task Force: Duke University, the Environmental Defense Fund, Johnson and Johnson, McDonald's, the Prudential Insurance Company of America, and Time Inc. Commissioner: No inf.
Covered region	USA
Study characterisation	Comparison of virgin paper and recycled paper systems 1 tonne of newsprint/corrugated/cardboard/office paper handled for disposal/recycling

Scenarios			**Recycling (100%) - versus landfilling (100%)**	**Recycling (100%) - versus incineration (100%)**	**Recycling (100%) - versus landfilling (79%) and incineration (21%)**
Scenario no.			8.1	8.2	8.3
Paper /cardboard type			Newsprint	Newsprint	Newsprint
System boundaries					
Raw materials / forestry	1	Alternative use of land/wood included?	No	no	no
	2	Saved wood used for energy?	no	no	no
	3	Wood marginal	no	no	no
Paper production	4	Virgin paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	5	- Steam marginal	Wood. Marginals not included	Wood. Marginals not included	Wood. Marginals not included
	6	Recovered paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	7	- Steam marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	8	Energy export from virgin paper included?	yes	yes	yes
Disposal	9	Main alternative to recycling	landfilling (100%)	incineration (100%)	79% landfilling +21% incineration
	10	Emissions from landfill included?	Yes, CH_4 and CO_2	Yes, CH_4 and CO_2	Yes, CH_4 and CO_2
	11	Energy from incineration substitutes heat?	no	no	no
	12	Energy from incineration substitutes electricity?	yes	yes	yes
	13	Alternative use of incineration capacity included?	No inf.	No inf.	No inf.
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	0	0	0
Impact Assessment: Relative difference: (recycling-alternative option)/alternative option					
Energy			- 45 %	- 32 %	- 43 %
Resource consumption		Fossil fuels	- 37 %	- 8 %	- 32 %
		Others	Water: - 7 %	Water: - 7 %	Water: - 7 %
Global warming			- 61 %	- 25.4 %	- 57 %
CO_2 saving (ton CO_2-eq./ton paper)			- 2.5	- 0.5	- 2.1
Other energy-related impacts *			- 45 %	- 30 %	- 42 %
Toxicity			- 51 %	- 51 %	- 51 %
Waste			- 60 %	+ 22 %	- 54 %
Other (e.g. biodiversity, wastewater impacts)			Wastewater: COD: - 36 %	Wastewater: COD: - 36 %	Wastewater: COD: - 36 %

NOTES:
* acidification, nutrient enrichment, photochemical ozone creation (POCP). CH4 from anaerobic biodegradation also included in POCP

Scenarios			**Recycling (100%) - versus landfilling (100%)**	**Recycling (100%) - versus incineration (100%)**	**Recycling (100%) - versus landfilling (79%) and incineration (21%)**
Scenario no.			8.4	8.5	8.6
Paper /cardboard type			Corrugated	Corrugated	Corrugated
System boundaries					
Raw materials / forestry	1	Alternative use of land/wood included?	no	no	no
	2	Saved wood used for energy?	no	no	no
	3	Wood marginal	no	no	no
Paper production	4	Virgin paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	5	- Steam marginal	Wood. Marginals not included	Wood. Marginals not included	Wood. Marginals not included
	6	Recovered paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	7	- Steam marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	8	Energy export from virgin paper included?	yes	yes	yes
Disposal	9	Main alternative to recycling	landfilling (100%)	incineration (100%)	79% landfilling +21% incineration
	10	Emissions from landfill included?	Yes, CH4 and CO2	Yes, CH4 and CO2	Yes, CH4 and CO2
	11	Energy from incineration substitutes heat?	no	no	no
	12	Energy from incineration substitutes electricity?	yes	yes	yes
	13	Alternative use of incineration capacity incl.?	No inf.	No inf.	No inf.
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	0	0	0
Impact Assessment: Relative difference: (recycling-alternative option)/alternative option					
Energy			- 33 %	- 13 %	- 30 %
Resource consumption		Fossil fuels	+ 14 %	+ 138 %	+ 28 %
		Others	Water: - 82 %	Water: - 82 %	Water: - 82 %
Global warming			- 46 %	+ 57 %	- 38 %
CO_2 saving (ton CO_2-eq./ton paper)			- 1.3	+ 0.6	- 0.9
Other energy-related impacts *			- 20 %	+ 20 %	- 15 %
Toxicity			- 95 %	- 95 %	- 95 %
Waste			- 77 %	+ 32 %	- 72 %
Other (e.g. biodiversity, wastewater impacts)			Wastewater: COD: - 95 %	Wastewater: COD: - 95 %	Wastewater: COD: - 95 %

NOTES:
* acidification, nutrient enrichment, photochemical ozone creation (POCP). CH4 from anaerobic biodegradation also included in POCP

Scenarios			Recycling (100%) - versus landfilling (100%)	Recycling (100%) - versus incineration (100%)	Recycling (100%) - versus landfilling (79%) and incineration (21%)
Scenario no.			8.7	8.8	8.9
Paper /cardboard type			CUK paperboard	CUK paperboard	CUK paperboard
System boundaries					
Raw materials / forestry	1	Alternative use of land/wood included?	no	no	no
	2	Saved wood used for energy?	no	no	no
	3	Wood marginal	no	no	no
Paper production	4	Virgin paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	5	- Steam marginal	Wood. Marginals not included	Wood. Marginals not included	Wood. Marginals not included
	6	Recovered paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	7	- Steam marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	8	Energy export from virgin paper included?	yes	yes	yes
Disposal	9	Main alternative to recycling	landfilling (100%)	incineration (100%)	79% landfilling +21% incineration
	10	Emissions from landfill included?	Yes, CH4 and CO2	Yes, CH4 and CO2	Yes, CH4 and CO2
	11	Energy from incineration substitutes heat?	no	no	no
	12	Energy from incineration substitutes electricity?	yes	yes	yes
	13	Alternative use of incineration capacity incl.?	No inf.	No inf.	No inf.
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	0	0	0
Impact Assessment: Relative difference: (recycling-alternative option)/alternative option					
Energy			- 41 %	- 23 %	- 38 %
Resource consumption		Fossil fuels	+ 3 %	+ 156 %	+ 17 %
		Others	Water: - 83 %	Water: - 83 %	Water: - 83 %
Global warming			- 48 %	+ 91 %	- 36 %
CO_2 saving (ton CO_2-eq./ton paper)			- 1.2	+ 0.7	- 0.8
Other energy-related impacts *			- 15 %	+ 30 %	- 10 %
Toxicity			- 90 %	- 90 %	- 90 %
Waste			- 75 %	+ 40 %	- 69 %
Other (e.g. biodiversity, wastewater impacts)			Wastewater: COD: - 95 %	Wastewater: COD: - 95 %	Wastewater: COD: - 95 %

NOTES:
* acidification, nutrient enrichment, photochemical ozone creation (POCP). CH4 from anaerobic biodegradation also included in POCP

Scenarios			**Recycling (100%) - versus landfilling (100%)**	**Recycling (100%) - versus incineration (100%)**	**Recycling (100%) - versus landfilling (79%) and incineration (21%)**
Scenario no.			8.10	8.11	8.12
Paper /cardboard type			SBS paperboard	SBS paperboard	SBS paperboard
System boundaries					
Raw materials / forestry	1	Alternative use of land/wood included?	no	no	no
	2	Saved wood used for energy?	no	no	no
	3	Wood marginal	no	no	no
Paper production	4	Virgin paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	5	- Steam marginal	Wood. Marginals not included	Wood. Marginals not included	Wood. Marginals not included
	6	Recovered paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	7	- Steam marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	8	Energy export from virgin paper included?	yes	yes	yes
Disposal	9	Main alternative to recycling	landfilling (100%)	incineration (100%)	79% landfilling +21% incineration
	10	Emissions from landfill included?	Yes, CH4 and CO2	Yes, CH4 and CO2	Yes, CH4 and CO2
	11	Energy from incineration substitutes heat?	no	no	no
	12	Energy from incineration substitutes electricity?	yes	yes	yes
	13	Alternative use of incineration capacity incl.?	No inf.	No inf.	No inf.
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	0	0	0
Impact Assessment: Relative difference: (recycling-alternative option)/alternative option					
Energy			- 58 %	- 49 %	- 57 %
Resource consumption		Fossil fuels	- 15 %	+ 70 %	- 6 %
		Others	Water: - 91 %	Water: - 91 %	Water: - 91 %
Global warming			- 51 %	+ 38 %	- 44 %
CO_2 saving (ton CO_2-eq./ton paper)			- 1.5	+ 0.4	- 1.1
Other energy-related impacts *			- 40 %	- 20 %	- 30 %
Toxicity			- 95 %	- 95 %	- 95 %
Waste			- 78 %	- 23 %	- 74 %
Other (e.g. biodiversity, wastewater impacts)			Wastewater: COD: - 98 %	Wastewater: COD: - 98 %	Wastewater: COD: - 98 %

NOTES:
* acidification, nutrient enrichment, photochemical ozone creation (POCP). CH4 from anaerobic biodegradation also included in POCP

Scenarios			Recycling - versus landfilling (100%)	Recycling - versus incineration (100%)	Recycling - versus landfilling (79%) and incineration (21%)
			8.13	8.14	8.15
Paper /cardboard type			Office paper	Office paper	Office paper
System boundaries					
Raw materials / forestry	1	Alternative use of land/wood included?	no	no	no
	2	Saved wood used for energy?	no	no	no
	3	Wood marginal	no	no	no
Paper production	4	Virgin paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	5	- Steam marginal	Wood. Marginals not included	Wood. Marginals not included	Wood. Marginals not included
	6	Recovered paper - Electricity marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	7	- Steam marginal	Fossil. Marginals not included	Fossil. Marginals not included	Fossil. Marginals not included
	8	Energy export from virgin paper included?	yes	yes	yes
Disposal	9	Main alternative to recycling	landfilling (100%)	incineration (100%)	79% landfilling +21% incineration
	10	Emissions from landfill included?	Yes, CH_4 and CO_2	Yes, CH_4 and CO_2	Yes, CH_4 and CO_2
	11	Energy from incineration substitutes heat?	no	no	no
	12	Energy from incineration substitutes electricity?	yes	yes	yes
	13	Alternative use of incineration capacity incl.?	Yes. MSW	Yes. MSW	Yes. MSW
	14	In which ratio does recycled paper substitute virgin paper? (1:1 or 1:0.8 or 1:0.5 or other)	0	0	0
Impact Assessment: Relative difference: (recycling-alternative option)/alternative option					
Energy			- 46 %	- 35 %	- 44 %
Resource consumption	Fossil fuels		+ 8 %	+ 101 %	+ 20 %
	Others		Water: - 49 %	Water: - 49 %	Water: - 49 %
Global warming			- 46 %	+ 46 %	- 38 %
CO_2 saving (ton CO_2-eq./ton paper)			- 1.4	+ 0.5	- 1.0
Other energy-related impacts *			- 30 %	- 5 %	- 20 %
Toxicity			- 85 %	- 85 %	- 85 %
Waste			- 56 %	+ 15 %	- 49 %
Other (e.g. biodiversity, wastewater impacts)			Wastewater: COD: - 70 %	Wastewater: COD: - 70 %	Wastewater: COD: - 70 %

NOTES:
* acidification, nutrient enrichment, photochemical ozone creation (POCP). CH4 from anaerobic biodegradation also included in POCP

Study	**S9 -** Frees et al. (2004): Update of the knowledge basis on the environmental impact of paper and cardboard recycling
Study conductor/ commissioner	Conductor: the Institute for Product Development and Danish Technological Institute Commissioner: the Danish Environmental Protection Agency
Covered region	Denmark
Study characterisation	Update of information about paper recycling and disposal In the scenarios with 100 % recycling and 100 % incineration: 1 kg of paper/board collected in Denmark in year 2001. In the rest of scenarios: total use of paper in Denmark in 2001.

Scenario			Biomass unlimited – no alternative use of land/wood								
Subscenario			Recycling (100%) - Base case	Recycling (100%) - alternative use of inciner. capacity	Recycling (100%) - only heat production from incineration	Recycling (100%) - Base case	Recycling (100%) Alternative use of inciner. capacity	Recycling (100%) - Only heat production from incineration	Recycling (100%) - Base case	Recycling (100%) - Alternative use of inciner. capacity	Recycling (100%) - Only heat production from incineration
Subscenario no.			9.1	9.2	9.3	9.4	9.5	9.6	9.7	9.8	9.9
Paper/pulp type			Mixed paper	Mixed paper	Mixed paper	Newsp. & magaz.	Newsp. & magaz.	Newsp. & magaz.	Corr. Cardb.	Corr. Cardb.	Corr. Cardb.
System boundaries											
Raw mat./ forestry	1	Alternative use of land/wood included?	no	no	no	no	no	no	no	no	no
	2	Saved wood used for energy?	no	no	no	no	no	no	no	no	no
	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	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration
	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 incl.?	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)	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8
	15	Disposal of de-inking sludge included?	yes	yes	yes	yes	yes	yes	yes	yes	yes
Impact Assessment: Relative difference: (recycling-incineration)/incineration											
Energy			- 45 %	- 65 %	- 49 %	- 55 %	- 77 %	- 59 %	- 46 %	- 69 %	- 51 %
Resource consumption (fossil fuels)			+ 45 %	- 20 %	+ 13 %	- 11 %	- 57 %	- 29 %	+ 1066 %	- 92 %	+ 61 %
Global warming			+ 32 %	- 189 %	+ 3 %	- 16 %	- 175 %	- 32 %	+ 695 %	- 1240 %	+ 108 %
CO_2 saving (ton CO_2-eq./ton paper)			+ 0.25	- 1.5	+ 0.03	- 0.2	- 1.9	- 0.4	+ 0.6	- 1.1	+ 0.4
Other energy-related impacts *			- 51 %	- 37 %	- 54 %	- 59 %	- 41 %	- 63 %	+ 640 %	- 5 %	+ 571 %
Toxicity			No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
Waste			- 80 %	- 57 %	- 80 %	- 51 %	+ 29 %	- 52 %	- 41 %	+ 113 %	- 44 %
Other			No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.

Scenario			Biomass limited – wood marginal = fossil fuel								
Subscenario			Recycling (100%) - Base case	Recycling (100%) - alternative use of inciner. capacity	Recycling (100%) - only heat production from incineration	Recycling (100%) - Base case	Recycling (100%) Alternative use of inciner. capacity	Recycling (100%) - Only heat production from incineration	Recycling (100%) - Base case	Recycling (100%) - Alternative use of inciner. capacity	Recycling (100%) - Only heat production from incineration
Subscenario no.			9.10	9.11	9.12	9.13	9.14	9.15	9.16	9.17	9.18
Paper/pulp type			Mixed paper	Mixed paper	Mixed paper	Newsp. & magaz.	Newsp. & magaz.	Newsp. & magaz.	Corr. Cardb.	Corr. Cardb.	Corr. Cardb.
System boundaries											
Raw mat./ forestry	1	Alternative use of land/wood included?	no	no	no	no	no	no	no	no	no
	2	Saved wood used for energy?	no	no	no	no	no	no	no	no	no
	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	Incine -ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration	Incine-ration
	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 incin-eration capacity incl.?	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)	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8	1 : 0.8
	15	Disposal of de-inking sludge included?	yes	yes	yes	yes	yes	yes	yes	yes	yes
Impact Assessment: Relative difference: (recycling-incineration)/incineration											
Energy			- 45 %	- 65 %	- 55 %	- 54 %	- 76 %	- 64 %	- 46 %	- 67 %	- 57 %
Resource consumption (fossil fuels)			- 43 %	- 62 %	- 52 %	- 52 %	- 73 %	- 62 %	- 49 %	- 72 %	- 61 %
Global warming			- 47 %	- 109 %	- 56 %	- 55 %	- 126 %	- 64 %	- 43 %	- 116 %	- 55 %
CO_2 saving (ton CO_2-eq./ton paper)			- 1.3	- 3.0	- 1.9	- 1.3	- 3.0	- 2.0	- 1.0	- 2.7	- 1.7
Other energy-related impacts *			- 71 %	- 68 %	- 73 %	- 80 %	- 75 %	- 81 %	- 65 %	- 61 %	- 66 %
Toxicity			No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
Waste			- 80 %	- 66 %	- 80 %	- 75 %	- 47 %	- 75 %	- 69 %	- 45 %	- 70 %
Other			No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.

NOTES:
* acidification, nutrient enrichment, photochemical ozone creation (POCP). CH4 from anaerobic biodegradation also included in POCP

Study:

GL-1. Craighill and Powell (1996) Lifecycle assessment and economic evaluation of recycling: a case study.

Study commisioner:

EcoRecycle Victoria, Australia

Comments:

Decision to support: evaluate the environmental performance of 1kg glass in waste in Milton Keynes, UK, in a recycling scenario vs. landfilling (no scenario with incineration)

FU: management of 1 kg of glass in waste.

Scenario	Glas Packaging in waste, max. recycling (landfilling of 2.5%residuals) vs 100% landfilling
Subscenario	N.a
Subscenario no.	GL-1.1
Material type	Glass packaging

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin glass, unspecified origin
	2	Electricity marginal: which?	Average mix in UK, 1995 (not specified)
	3	Steam marginal: which?	No inf.
	4	Co-products dealt with?	N.a.
	Secondary material		
	5	Material marginal	Other secondary glass, unspecified origin or composition
	6	Electricity marginal: which?	Average mix in UK, 1995 (not specified)
	7	Steam marginal: which?	No inf.
	8	Co-products dealt with?	N.a.
Material recovery	9	Product dependent material recovery included?	No inf.
	10	Type of product dependent material recovery	No inf.
Material disposal	11	Disposal comparison	Recycling (2.5% residuals to landfilling) vs. 100% landfilling
	12	Emissions from landfill included?	To air: Yes (but not applicable to glass)To water: No info.
	13	Energy from incineration substitutes heat?	N.a.
	14	Energy from incineration substitutes electricity?	N.a.
	15	Alternative use of incineration capacity included?	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.
Resource consumption	No Inf.
Global warming	-45%
Saving, [tonne CO2 eq. / tonne glass]	1,12
Other energy nutrient enrichment	-32%
Toxicity	No Inf.
Waste	No Inf.
Other	
Acidification	-41%

Values are rounded up (or down) to nearest multiplum of 1%

Study:

GL-2. Enviros, 2004, Glass Recycling - Life Cycle Carbon Dioxide Emissions

Study commisioner:

British Glass Manufacturers Confederation

Comments:

Study of the link betwen glass recycling and climate change. Six different recycling options are analysed entailing seven scenarios

FU: 1 tonne of recycled glass.

Scenario	Recycling of glas packaging waste vs 100% landfilling						
Subscenario	Landfill	Landfill	Landfill	Landfill	Landfill	Landfill	Landfill
Subscenario no.	GL-2.1	GL-2.2	GL-2.3	GL-2.4	GL-2.5	GL-2.6	GL-2.7
Material type	Glass packaging	Glass packaging	Glass packaging	Glass packaging	Glass packaging	Glass packaging	Glass packaging

System boundaries

			GL-2.1	GL-2.2	GL-2.3	GL-2.4	GL-2.5	GL-2.6	GL-2.7
Material production	*Virgin material*								
	1	Material marginal	UK virgin glass packaging	UK Virgin glass packaging	UK virgin glass packaging/Virgin glass fibre	UK virgin glass packaging/virgin aggregate	UK virgin glass packaging/virgin filtration media	UK virgin glass packaging/virgin shot blast abrasive	UK virgin glass packaging/clay brick manufacturing
	2	Electricity marginal: which?	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
	3	Steam marginal: which?	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
	4	Co-products dealt with?	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.
	Secondary material								
	5	Material marginal	Glass collected in the UK via kerbside or bottle banks	Glass collected in the UK via kerbside or bottle banks	Glass collected in the UK via kerbside or bottle banks	Glass collected in the UK via kerbside or bottle banks	Glass collected in the UK via kerbside or bottle banks	Glass collected in the UK via kerbside or bottle banks	Glass collected in the UK via kerbside or bottle banks
	6	Electricity marginal: which?	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
	7	Steam marginal: which?	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
	8	Co-products dealt with?	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Closed loop glass manufacturing	Closed loop glass manufacturing	Glass fibre manufacturing	Production of aggregates	Production of filtration media	Production of shot blast abrasive	Clay brick manufacturing
Material disposal	11	Disposal comparison	Recycling as feedstock for new glass manufacture	Recycling as feedstock for new glass manufacture (exported glass)	Recycling as Feedstock for glass fibre manufacture	Recycling as aggregate	Recycling as filtration media	Recycling as shot blast abrasive	Recycling in clay brick manufacturing
	12	Emissions from landfill included?	No	No	No	No	No	No	No
	13	Energy from incineration substitutes heat?	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.
	14	Energy from incineration substitutes electricity?	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.
	15	Alternative use of incineration capacity included?	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

	GL-2.1	GL-2.2	GL-2.3	GL-2.4	GL-2.5	GL-2.6	GL-2.7
Energy	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-37%	-34%	-33%	0.2%	5%	-2%	-8%
Savings (tonne CO2-eq/tonne glas	0.31	0.29	0.28	-0.002	-0.04	0.02	0.07
Other ener nutrient enrichment	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Waste	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.

Study:

GL-3. Grant et al (2001) LCA for paper and packaging waste management scenarios in Victoria

Study commisioner:

EcoRecycle Victoria, Australia

Comments:

Decision to support: evaluate the environmental performance of glass packaging recycling vs. landfilling (no scenario with incineration) FU: management of the recyclable fraction of glass packaging from the average Melbourne household in one week (1.17kg

Scenario	Glass Packaging recycling, 72.1% vs. Landfilling
Subscenario	N.a.
Subscenario no.	GL-3.1
Material type	Glass packaging for food and beverages

System boundaries

Material production	*Virgin material*		
	1	Material marginal	A batch consisting of silica sand (72%), soda ash (14%), limestone (12%) and other ingredients (2%), at ACI Glass, Spotswood, Australia
	2	Electricity marginal: which?	Average in SE Australia: 52.6% coal, 35.9% brown coal, 6.3% nat.gas, 5.2% hydro, 0.0003% wind, 0.0193% Oil
	3	Steam marginal: which?	No inf.
	4	Co-products dealt with?	N.a.
	Secondary material		
	5	Material marginal	Cullet to glass beneficiation plant at Laverton North, Australia
	6	Electricity marginal: which?	Average in SE Australia: 52.6% coal, 35.9% brown coal, 6.3% nat.gas, 5.2% hydro, 0.0003% wind, 0.0193% Oil
	7	Steam marginal: which?	No inf.
	8	Co-products dealt with?	N.a.
Material recovery	9	Product dependent material recovery included?	Yes
	10	Type of product dependent material recovery	A batch consisting of silica sand (72%), soda ash (14%), limestone (12%) and other ingredients (2%), at ACI Glass, Spotswood, Australia
Material disposal	11	Disposal comparison	Glass Packaging recycling (72.1%) vs. 100% landfilling
	12	Emissions from landfill included?	Yes
	13	Energy from incineration substitutes heat?	Yes, but not applicable to glass
	14	Energy from incineration substitutes electricity?	Yes, but not applicable to glass
	15	Alternative use of incineration capacity included?	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	Substitutes 1:0.98 a batch consisting of silica sand (72%), soda ash (14%), limestone (12%) and other ingredients (2%), at ACI Glass, Spotswood, Australia

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy		-80%
Resource coı	water	No Inf.
Global warming		-79%
Savings (tonne CO2-eq/tonne glass)		0,48
Other energy related impacts		No Inf.
Toxicity		No Inf.
Waste		-99%
Other	smog precursors	-81%

Values are rounded up (or down) to nearest multiplum of 1%

Study:

GL-4 Muñoz et al. (2004), LCA application to integrated waste management planning in Gipuzkoa (Spain). Int. J. of LCA 9(4) 272-280. Background report: LCA applied to different alternatives for the management of MSW and sewage sludge in the waste managemen

Study commisioner:

Diputación Foral de Gipuzkoa (Regional Government of Gipuzkoa)

Comments:

The purpose is to compare alternatives for the handling of MSW generated in 2016

Scenario	Glass waste collection and recycling vs. landfilling
Subscenario	N.a.
Subscenario no.	GL-4.1
Material type	Glass for packaging - no specified quality

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin glass ingredients (1)
	2	Electricity marginal: which?	Prediction of marginal supply mix in 2016: 70% hydro, 20% coal, 5% nat.gas, 5% other
	3	Steam marginal: which?	Fossil (natural gas)
	4	Co-products dealt with?	N.a.
	Secondary material		
	5	Material marginal	Glass cullets (2)
	6	Electricity marginal: which?	Prediction of marginal supply mix in 2016: 70% hydro, 20% coal, 5% nat.gas, 5% other
	7	Steam marginal: which?	Fossil (natural gas)
	8	Co-products dealt with?	N.a.
Material recovery	9	Product dependent material recovery included?	No inf.
	10	Type of product dependent material recovery	No inf.
Material disposal	11	Disposal comparison	100% Recycling vs. 100% landfilling
	12	Emissions from landfill included?	Yes, but not applicable to glass
	13	Energy from incineration substitutes heat?	Yes, but not applicable to glass
	14	Energy from incineration substitutes electricity?	Yes, but not applicable to glass
	15	Alternative use of incineration capacity included?	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy		-89%
Resource coı	Water consumption	-98%
Global warming		-92%
Saving, [tonne CO2 eq. / tonne steel]		0,48
Other energy	Acidification	-69%
	Eutrophization	-58%
	Photochemical oxidant formatior	-64%
Toxicity	Human toxicity	-67%
Waste		-97%
Other, VOC	Ozone depletion	-38%

Values are rounded up (or down) to nearest multiplum of 1%

(1) Ingredients of glass as defined in the following databases:
Silica: BUWAL 132
Calcium carbonate: BUWAL 250
Sodium carbonate: Bergh and Jurgens database
Dolomite: BUWAL 132
Feldspar: BUWAL 132

(2) Composition of cullets in IVAM LCA data 2.0 and BUWAL 132 databases

Study:

GL-5 Pommer, K.; Wesnaes, M.S. (1995), Environmental description (kortlægning) of Packaging Systems for Beer and Soft Drinks (in Danish), Main report, Danish EPA (Work Report no. 72)

Study commisioner:

Danish EPA

Comments:

The purpose is to compare materials for packaging

Scenario	Packaging systems	Packaging systems
Subscenario	Recycling vs Incineration	Recycling vs Incineration
Subscenario no.	GL-5.1	GL-5.2
Material type	Refillable coloured beer bottles	One-use glass bottles,coloured

System boundaries

Material production	*Virgin material*			
	1	Material marginal	Glassworks, Holmegaard Glassworks, Denmark	Glassworks, Holmegaard Glassworks, Denmark
	2	Electricity marginal: which?	Fossil (Coal)	Fossil (Coal)
	3	Steam marginal: which?	Fossil (Coal)	Fossil (Coal)
	4	Co-products dealt with?	N.a.	N.a.
	Secondary material			
	5	Material marginal	Glass cullets mix used in Holmegaard Glassworks, Denmark	Glass cullets mix used in Holmegaard Glassworks, Denmark
	6	Electricity marginal: which?	Fossil (Coal)	Fossil (Coal)
	7	Steam marginal: which?	Fossil (Coal)	Fossil (Coal)
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	No	No
	10	Type of product dependent material recovery	N.a.	N.a.
Material disposal	11	Disposal comparison	100% Recycling vs. 100% incineration followed by slag landfilling	100% Recycling vs. 100% incineration followed by slag landfilling
	12	Emissions from landfill included?	No. Assumed of little magnitude	No. Assumed of little magnitude
	13	Energy from incineration substitutes heat?	N.a.	N.a.
	14	Energy from incineration substitutes electricity?	N.a.	N.a.
	15	Alternative use of incineration capacity included?	No Inf.	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.	No inf.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-62%	-3%
Resource consumption	No Inf.	No Inf.
Global warming	No Inf.	No Inf.
Saving, [tonne CO2 eq. / tonne glass]	0,62	0,03
Other energy related impacts	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other, VOC	No Inf.	No Inf.

Values are rounded up (or down) to nearest multiplum of 1%

Study:

GL-6 RDC-Coopers & Lybrand, 1997, Eco-balances for policy-making in the domain of packaging and packaging waste
Study commisioner:
The European Commission
Comments: FU: 1kg of household packaging material

Scenario	Glass recycling vs energy recovery			
Subscenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario
Subscenario no.	GL-6.1	GL-6.2	GL-6.3	GL-6.4
Material type	Glass packaging	Glass packaging	Glass packaging	Glass packaging

System boundaries

Material production	*Virgin material*					
	1	Material marginal	Primary glass production (incl. 65% recycled)	Primary glass production (incl. 65% recycled)	Primary glass production (incl. 65% recycled)	Primary glass production (incl. 65% recycled)
	2	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	3	Steam marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	4	Co-products dealt with?	N.a.	N.a.	N.a.	N.a.
	Secondary material					
	5	Material marginal	Glass packaging waste from households	Glass packaging waste from households	Glass packaging waste from households	Glass packaging waste from households
	6	Electricity marginal: which?	No inf.**	No inf.**	No inf.**	No inf.**
	7	Steam marginal: which?	No inf.**	No inf.**	No inf.**	No inf.**
	8	Co-products dealt with?	N.a.	N.a.	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Optimistic recycling scenario	Optimistic recycling scenario	Pessimistic recycling scenario	Pessimistic recycling scenario
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	Yes, but not applicable to glass	Yes, but not applicable to glass	Yes, but not applicable to glass	Yes, but not applicable to glass
	14	Energy from incineration substitutes electricity?	Yes, but not applicable to glass	Yes, but not applicable to glass	Yes, but not applicable to glass	Yes, but not applicable to glass
	15	Alternative use of incineration capacity included?	No inf.	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1

* No specification - only reference to Buwal (1996): Ökoinventare für verpackungen.
** No specification of energy - only reference to RDC database (library and confidential studies from RDC) .

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-23%	-29%	-12%	-18%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-29%	-36%	-15%	-22%
Saving, [tonne CO2 eq. / tonne glass]	0,45	0,60	0,23	0,38
Other energy related impacts	-22%	-36%	12%	-8%
Toxicity	11%	16%	12%	17%
Waste	-78%	-78%	-78%	-78%
Other	-25%	-40%	10%	-11%

Values are rounded up (or down) to nearest multiplum of 1%

Study:

GL-7 RDC-Pira, 2003, Evaluation of costs and benefits for the achievement of reuse and recycling targets for the different packaging materials in the frame of the packaging and packaging waste directive 94/62/EC

Study commisioner:

The European Commission

Comments:

Values for comparison of waste management options have been extracted through own calculations based on data from annex 10 of the study

Scenario	Recycling of glass in MSW (bring system low population density)	
Subscenario	Landfill vs. Recycling	Incineration vs. recycling
Subscenario no.	GL-7.1	GL-7.2
Material type	Glass packaging	Glass packaging

System boundaries

Material production	*Virgin material*			
	1	Material marginal	Virgin glass, unspecified origin	Virgin glass, unspecified origin
	2	Electricity marginal: which?	No inf.*	No inf.*
	3	Steam marginal: which?	No inf.*	No inf.*
	4	Co-products dealt with?	N.a.	N.a.
	Secondary material			
	5	Material marginal	Glass beverage bottles from households	Glass beverage bottles from households
	6	Electricity marginal: which?	No inf.*	No inf.*
	7	Steam marginal: which?	No inf.*	No inf.*
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling	Recycling
	12	Emissions from landfill included?	Yes	N.a.
	13	Energy from incineration substitutes heat?	N.a.	Yes, but not applicable to glass
	14	Energy from incineration substitutes electricity?	N.a.	Yes, but not applicable to glass
	15	Alternative use of incineration capacity included?	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.	No inf.

* Details not directly available. Data in report is derived from UK EPA (2000)

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	The study concludes that recycling causes less impact than landfill or incineration	
Saving, [tonne CO2 eq. / tonne glass]	2,03	2,07
Other energy related impacts	The study concludes that recycling causes less impact than landfill or incineration	
Toxicity	The study concludes that recycling causes less impact than landfill or incineration	
Waste	The study concludes that recycling causes less impact than landfill or incineration	
Other	The study concludes that recycling causes less impact than landfill or incineration	

Values are rounded up (or down) to nearest multiplum of 1%

Study:
GL-8 Smith A, Brown K, Ogilvie S, Rushton K and Bates J, 2001, Waste Management Options and Climate Change.
Study commisioner:
The European Commission
Comments:
Investigates climate change impacts of options for managing MSW

Scenario	Recycling of glass in MSW	
Subscenario	Incineration	Landfill
Subscenario no.	GL-8.1	GL-8.2
Material type	MSW glass	MSW glass

System boundaries

Material production	*Virgin material*			
	1	Material marginal	EU average	EU average
	2	Electricity marginal: which?	Grid mix (not specified)*	Grid mix (not specified)*
	3	Steam marginal: which?	Average use mix (coke, oil and natural gas)*	Average use mix (coke, oil and natural gas)*
	4	Co-products dealt with?	N.a.	N.a.
	Secondary material			
	5	Material marginal	Marginal glass production	Marginal glass production
	6	Electricity marginal: which?	Grid mix (not specified)*	Grid mix (not specified)*
	7	Steam marginal: which?	Average use mix (coke, oil and natural gas)*	Average use mix (coke, oil and natural gas)*
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling in container manufacture	Recycling in container manufacture
	12	Emissions from landfill included?	Yes	Yes
	13	Energy from incineration substitutes heat?	Yes (EU average industrial heat mix - but not applicable to glass)	N.a.
	14	Energy from incineration substitutes electricity?	Yes (average EU generation - but not applicable to glass)	N.a.
	15	Alternative use of incineration capacity included?	No inf.	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:0.95	1:0.95

* Data from the EA/Chem Systems life cycle inventory (Chem Systems, 1997)

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	The study concludes that recycling causes less impact than landfill or incineration	
Saving, [tonne CO2 eq. / tonne glass]	0,28	0,26
Other energy related impacts	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Values are rounded up (or down) to nearest multiplum of 1%

Study:
GL-9 Tillman A-M, Baumann H, Eriksson E and Rydberg T (1991). Packaging and the Environment – Life Cycle assessments of packaging
Study commisioner:
Swedish commission on Packaging
Comments:
1) Emissions from electricity production not included.
2) Electrical energy counted separately as direct energy, not primary energy.
3) Recycled material may be interpreted as if it substitutes 100 % primary material.

Scenario	70% recycling of glass	97% reuse of glass
Subscenario	Landfilling	Landfilling
Subscenario no.	GL-9.1	GL-9.2
Material type	Packaging glass	Packaging glass

System boundaries

Material production	*Virgin material*			
	1	Material marginal	Swedish glass production. Soda: 50% natural soda from the USA, 50% Solvay soda	Swedish glass production. Soda: 50% natural soda from the USA, 50% Solvay soda
	2	Electricity marginal: which?	Swedish average : 49%hydro, 45%nuclear, 6% fossil	Swedish average : 49%hydro, 45%nuclear, 6% fossil
	3	Steam marginal: which?	No inf.	No inf.
	4	Co-products dealt with?	N.a.	N.a.
	Secondary material			
	5	Material marginal	No inf.	No inf. (same as new product ?)
	6	Electricity marginal: which?	No inf.	No inf. (same as new product ?)
	7	Steam marginal: which?	No inf.	No inf. (same as new product ?)
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	Yes	Yes
	10	Type of product dependent material recovery	Other packaging glass waste from swedish packaging is substituted	Reuse of glass bottles. Washing.
Material disposal	11	Disposal comparison	70% Recycling, 30% Landfilling vs. 100% Landfilling	93% Reuse, 7% Landfilling vs. 100% Landfilling
	12	Emissions from landfill included?	No	No
	13	Energy from incineration substitutes heat?	Yes, but not applicable to glass	Yes, but not applicable to glass
	14	Energy from incineration substitutes electricity?	Yes, but not applicable to glass	Yes, but not applicable to glass
	15	Alternative use of incineration capacity included?	Yes. Landfill	Yes. Landfill
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No Inf.	No Inf.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	power	-33%	-89%
	heat	-20%	-84%
Global warm	CO2	-30%	-86%
	CO	-24%	-56%
Saving, [tonne CO2 eq. / tonne glass]		0,28	0,57
Other energy	NOx	-8%	-84%
	SO2	-26%	-82%
Toxicity	oil	-3%	-93%
	phenol	-38%	-38%
	COD	-47%	-35%
Waste	ashes	-69%	38%
	total waste	-70%	-97%
Other	particulates-air	-13%	-84%
	tot-N	-33%	-33%

Study:

GL-10 USEPA, 2002, Solid Waste Management And Greenhouse Gases. A Life-Cycle Assessment of Emissions and Sinks

Study commisioner:

United States Environment Protection Agency

Comments:

Development of material-specific GHG emission factors that can be used to account for the climate change benefits of waste management practices. Emissions counted from a Raw Materials Extraction Reference Point

Scenario	Glass recycling vs. Incineration	
Subscenario	Landfill	Incineration
Subscenario no.	GL-10.1	GL-10.2
Material type	Glass in MSW	Glass in MSW

System boundaries

Material production	*Virgin material*			
	1	Material marginal	Virgin glass (US average)	Virgin glass (US average)
	2	Electricity marginal: which?	US average fossil fuel mix	US average fossil fuel mix
	3	Steam marginal: which?	No inf.	No inf.
	4	Co-products dealt with?	N.a.	N.a.
	Secondary material			
	5	Material marginal	US average conditions	US average conditions
	6	Electricity marginal: which?	US average grid mix (including fossil fuels, biomass, hydropower and nuclear power)	US average grid mix (including fossil fuels, biomass, hydropower and nuclear power)
	7	Steam marginal: which?	No inf.	No inf.
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling	Recycling
	12	Emissions from landfill included?	Yes	Yes
	13	Energy from incineration substitutes heat?	N.a.	No
	14	Energy from incineration substitutes electricity?	N.a.	Yes (USI average fossil fuel mix - but not applicable to glass)
	15	Alternative use of incineration capacity included?	N.a.	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1;0.88	1;0.88

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	-59%	-60%
Saving, [tonne CO2 eq. / tonne glass]	0,32	0,33
Other energy related impacts	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Values are rounded up (or down) to nearest multiplum of 1%

Study:

GL-11: Edwards, D.W.; Schelling, J. (1999), Municipal Waste Life Cycle Assessment Part 2: Transport Analysis and Glass Case Study,
Process Safety and Environmental Protection: Vol.77 p. 259-274
Study commisioner:
No inf.
Comments:
Issue addressed: Savings due to recycling, compared to incineration and to landfill

Scenario	Recycling of glass	
Subscenario	Landfill	Incineration
Subscenario no.	GL-11.1	GL-11.2
Material type	Glass packaging	Glass packaging

System boundaries

Material production		*Virgin material*		
	1	Material marginal	UK average	UK average
	2	Electricity marginal: which?	Average UK mix in 1990 (primarily fossil)	Average UK mix in 1990 (primarily fossil)
	3	Steam marginal: which?	Average fuel distribution for steam in western Europe	Average fuel distribution for steam in western Europe
	4	Co-products dealt with?	N.a.	N.a.
		Secondary material		
	5	Material marginal	UK glass collection	UK glass collection
	6	Electricity marginal: which?	Average UK mix in 1990 (primarily fossil)	Average UK mix in 1990 (primarily fossil)
	7	Steam marginal: which?	Average fuel distribution for steam in western Europe	Average fuel distribution for steam in western Europe
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	Yes	yes
	10	Type of product dependent material recovery	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling	Recycling
	12	Emissions from landfill included?	Yes (equal to zero)	Yes (equal to zero)
	13	Energy from incineration substitutes heat?	N.a.	Yes (but not applicable to glass)
	14	Energy from incineration substitutes electricity?	N.a.	Yes (but not applicable to glass)
	15	Alternative use of incineration capacity included?	N.a.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:0.96	1:0.96

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	The study concludes that recycling causes less impact than landfill or incineration	
Saving, [tonne CO2 eq. / tonne glass]	0,467	0,509
Other energy related impacts	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other, VOC	No Inf.	No Inf.

Values are rounded up (or down) to nearest multiplum of 1%

Study:
01 PVC Recovery Options Concept for Environmental and Economic System Analysis
Study commisioner:
VINYL 2010
Comments: FU: Processing and recovery of 1 t mixed cable waste input (after dismantling)

Scenario	Mixed cable waste	Mixed cable waste	Mixed cable waste	Mixed cable waste	Mixed cable waste
Subscenario	Incineration	Landfill	Incineration	Landfill	Landfill
Subscenario no.	1.1	1.2	1.3	1.4	1.5
Material type	PVC / PE	PVC / PE	PVC / PE	PVC / PE	PVC / PE

System boundaries

Material production		*Virgin material*					
	1	Material marginal	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
	2	Electricity marginal: which?	German mix.	German mix.	German mix.	German mix.	German mix.
	3	Steam marginal: Which?	Fossil (gas)	Fossil (gas)	Fossil (gas)	Fossil (gas)	Fossil (gas)
	4	Co-products dealt with?	No	No	No	No	No
		Recovered material					
	5	Material marginal: Which?	N.a.	N.a.	N.a.	N.a.	N.a.
	6	Electricity marginal: Which?	N.a.	N.a.	N.a.	N.a.	N.a.
	7	Steam marginal: Which?	N.a.	N.a.	N.a.	N.a.	N.a.
	8	Co-products dealt with?	N.a.	N.a.	N.a.	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	No	No	No	No	No
	10	Type of product dependent material recovery	N.a.	N.a.	N.a.	N.a.	N.a.
Material disposal	11	Disposal comparison	Recycling, Vinyloop	Recycling, Vinyloop	Recycling, Stigsnaes	Recycling, Stigsnaes	Incineration
	12	Emissions from landfill included?	Yes	Yes	Yes	Yes	Yes
	13	Energy from incineration substitutes heat?	Yes*	Yes*	Yes*	Yes*	Yes*
	14	Energy from incineration substitutes electricity?	Yes*	Yes*	Yes*	Yes*	Yes*
	15	Alternative use of incineration capacity incl.?	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1	1:1

*both electricity and heat, ratio not specified

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-39%	-49%	-15%	-29%	-17%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-43%	-22%	-30%	-4%	37%
Saving, [tonne CO_2 eq. / tonne plastics]. A negative value indicates a saving	-1,60	-0,60	-1,10	-0,10	1,00
Other energy related impacts, SO_2 eq.	-20%	-34%	-18%	-32%	-18%
Toxicity; water	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Waste	-98%	-99%	-99%	-100%	-58%
Other	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.

Study:

02 Recovery Options for Plastic Parts from End-of-Life Vehicles

Study commisioner:

APME, Brussels

Comments: FU: Treatment of one discrete plastic component in end-of life vehicles (ELV)

Scenario	Bumper from ELV	Bumper from ELV	Bumper from ELV	Bumper from ELV	Bumper from ELV
Subscenario	Incineration	Incineration (Cement Kiln)	Landfill	Landfill	Landfill
Subscenario no.	2.1	2.2	2.3	2.4	2.5
Material type	PP	PP	PP	PP	PP

System boundaries

Material production		*Virgin material*					
	1	Material marginal	APME data	APME data	APME data	APME data	APME data
	2	Electricity marginal: which?	W. European grid 2001	W. European grid 2001	W. European grid 2001	W. European grid 2001	W. European grid 2001
	3	Steam marginal: Which?	Generic data for EU-15	Generic data for EU-15	Generic data for EU-15	Generic data for EU-15	Generic data for EU-15
	4	Co-products dealt with?	No	No	No	No	No
		Recovered material					
	5	Material marginal: Which?	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
	6	Electricity marginal: Which?	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
	7	Steam marginal: Which?	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
	8	Co-products dealt with?	No	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Dismantling of parts from vehicle	Dismantling of parts from vehicle	Dismantling of parts from vehicle	Dismantling of parts from vehicle	Dismantling of parts from vehicle
Material disposal	11	Disposal comparison	Recycling	Recycling	Recycling	Incineration	Incineration (Cement Kiln)
	12	Emissions from landfill included?	Yes	Yes	Yes	Yes	Yes
	13	Energy from incineration substitutes heat?	Yes*	Yes*	Yes*	Yes*	Yes*
	14	Energy from incineration substitutes electricity?	Yes*	Yes*	Yes*	Yes*	Yes*
	15	Alternative use of incineration capacity incl.?	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1	1:1

*both electricity and heat, ratio not specified

Impact Assessment - e.g. recycling compared to incineration: (recycling -

Energy	-11%	-7%	-19%	-9%	-12%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-12%	-1%	-6%	7%	-5%
Saving, [tonne CO_2 eq. / tonne plastics]	-2,77	-0,13	-1,27	1,50	-1,15
Other energy related impacts, SO_2 eq.	-23%	-23%	-23%	0%	0%
Toxicity; water	-15%	-13%	-26%	-13%	-15%
Waste	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Other POCP	-6%	-6%	-6%	0%	0%

Study:

03 Life Cycle Assessment and Socio-economic Cost Benefit Analyses of the Treatment of Plastic Packaging Waste from Households in Norway.

Study commisioner:

Plastretur AS

Comments: FU: 1tonne of tonne of plastic packaging waste generated in households

Scenario	Plasticpackaging waste from households in Drammen	Plasticpackaging waste from households in Hamar
Subscenario	Landfill	Landfill
Subscenario no.	3.1	3.2
Material type	Waste plastics	

System boundaries

Material production	*Virgin material*			
	1	Material marginal: Which?	No inf.	No inf.
	2	Electricity marginal: Which?	No inf.	No inf.
	3	Steam marginal: Which?	No inf.	No inf.
	4	Co-products dealt with?	No inf.	No inf.
	Recovered material			
	5	Material marginal: Which?	No inf.	No inf.
	6	Electricity marginal: Which?	No inf.	No inf.
	7	Steam marginal: Which?	No inf.	No inf.
	8	Co-products dealt with?	No	No
Material recovery	9	Product dependent material recovery included?	No	No
	10	Type of product dependent material recovery	N.a.	N.a.
Material disposal	11	Disposal comparison	Recycling	Recycling
	12	Emissions from landfill included?	No inf.	No
	13	Energy from incineration substitutes heat?	Yes*	Yes*
	14	Energy from incineration substitutes electricity?	Yes*	Yes*
	15	Alternative use of incineration capacity incl.?	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1

*No specific information on substitution, however, energy production and application rate is included

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than landfill.
Saving, [tonne CO_2 eq. / tonne plastics] *)	-0,64	-0,82
Other energy related impacts, SO_2 eq.	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than landfill.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

*) Savings are calculated/estimated from a scenario of partial recycling

Study:

04 Life Cycle Assessment of Different Scenarios for Waste Treatment of a Plastic Bottle Used for Food Packaging.
Study commisioner:
Plastretur AS and Stabburet AS
Comments: FU: 1tonne of tonne of waste plastic bottles generated in households

Scenario		Plastic bottles in waste from households	Plastic bottles in waste from households
Subscenario		Landfill	Incineration
Subscenario no.		4.1	4.2
Material type		Waste plastics bottles	Waste plastics bottles

System boundaries

Material production		*Virgin material*		
	1	Material marginal: Which?	No inf.	No inf.
	2	Electricity marginal: which?	No inf.	No inf.
	3	Steam marginal: Which?	No inf.	No inf.
	4	Co-products dealt with?	No inf.	No inf.
		Recovered material		
	5	Material marginal: Which?	No inf.	No inf.
	6	Electricity marginal: Which?	No inf.	No inf.
	7	Steam marginal: Which?	No inf.	No inf.
	8	Co-products dealt with?	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes
	10	Type of product dependent material recovery	Washing of bottles	Washing of bottles
Material disposal	11	Disposal comparison	Recycling	Recycling
	12	Emissions from landfill included?	No inf.	No
	13	Energy from incineration substitutes heat?	Yes*	Yes*
	14	Energy from incineration substitutes electricity?	Yes*	Yes*
	15	Alternative use of incineration capacity incl.?	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1

*No specific information on substitution, however, energy production and application rate is included

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.
Saving, [tonne CO_2 eq. / tonne plastics]	-1,42	-1,09
Other energy related impacts, SO_2 eq.	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Study **05 Laurence Dolan, Life Cycle Assessment of Management Options for Waste Farm Plastics**
Study commisioner
Ministry for the Environment, New Zealand
Comments

Scenario	Waste farm plastics from Hawke's Bay			
Subscenario	Landfill	Incineration	Landfill	Incineration
Subscenario no.	5.1	5.2	5.3	5.4
Material type	HDPE	HDPE	LDPE	LDPE

System boundaries

Material production	*Virgin material*					
	1	Material marginal: Which?	No inf.	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	No inf.	No inf.	No inf.	No inf.
	3	Steam marginal: Which?	No inf.	No inf.	No inf.	No inf.
	4	Co-products dealt with?	No inf.	No inf.	No inf.	No inf.
	Recovered material					
	5	Material marginal: Which?	No inf.	No inf.	No inf.	No inf.
	6	Electricity marginal: Which?	No inf.	No inf.	No inf.	No inf.
	7	Steam marginal: Which?	No inf.	No inf.	No inf.	No inf.
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Washing of farm plastics	Washing of farm plastics	Washing of farm plastics	Washing of farm plastics
Material disposal	11	Disposal comparison	Recycling	Recycling	Recycling	Recycling
	12	Emissions from landfill included?	No, estimated to be negligible	No, estimated to be negligible	No, estimated to be negligible	No, estimated to be negligible
	13	Energy from incineration substitutes heat?	Yes, co-generation plant	Yes, co-generation plant	Yes, co-generation plant	Yes, co-generation plant
	14	Energy from incineration substitutes electricity?	Yes, co-generation plant	Yes, co-generation plant	Yes, co-generation plant	Yes, co-generation plant
	15	Alternative use of incineration capacity incl.?	No	No	No	No
	16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.	No Inf.	No Inf.
Resource consumption	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.
Global warming	do.	do.	do.	do.
Saving, [tonne CO2 eq. / tonne plastics]	-1,65	-2,57	-1,68	-2,60
Other energy related impacts (SO_2-eq.)	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.
Toxicity, human	do.	do.	do.	do.
Waste	No Inf.	No Inf.	No Inf.	No Inf.
Other (Eutrophication)	The study concludes that recycling causes **more** impact than landfill.	The study concludes that recycling causes **more** impact than incineration.	The study concludes that recycling causes **more** impact than landfill.	The study concludes that recycling causes **more** impact than incineration.

Study **05 Laurence Dolan, Life Cycle Assessment of Management Options for Waste Farm Plastics**
Study commisioner
Ministry for the Environment, New Zealand
Comments

Scenario	Waste farm plastics from Canterbury			
Subscenario	Landfill	Incineration	Landfill	Incineration
Subscenario no.	5.5	5.6	5.7	5.8
Material type	HDPE	HDPE	LDPE	LDPE

System boundaries

Material production	*Virgin material*					
	1	Material marginal: Which?	No inf.	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	No inf.	No inf.	No inf.	No inf.
	3	Steam marginal: Which?	No inf.	No inf.	No inf.	No inf.
	4	Co-products dealt with?	No inf.	No inf.	No inf.	No inf.
	Recovered material					
	5	Material marginal: Which?	No inf.	No inf.	No inf.	No inf.
	6	Steam marginal: Which?	No inf.	No inf.	No inf.	No inf.
	7	Steam marginal: Which?	No inf.	No inf.	No inf.	No inf.
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Washing of farm plastics	Washing of farm plastics	Washing of farm plastics	Washing of farm plastics
Material disposal	11	Disposal comparison	Recycling	Recycling	Recycling	Recycling
	12	Emissions from landfill included?	No, estimated to be negligible	No, estimated to be negligible	No, estimated to be negligible	No, estimated to be negligible
	13	Energy from incineration substitutes heat?	Yes, co-generation plant	Yes, co-generation plant	Yes, co-generation plant	Yes, co-generation plant
	14	Energy from incineration substitutes electricity?	Yes, co-generation plant	Yes, co-generation plant	Yes, co-generation plant	Yes, co-generation plant
	15	Alternative use of incineration capacity incl.?	No	No	No	No
	16	In which ratio does recycled material substitute virgin material? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.	No Inf.	No Inf.
Resource consumption	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.
Global warming	do.	do.	do.	do.
Saving, [tonne CO2 eq. / tonne plastics]	-1,61	-2,53	-2,39	-1,91
Other energy related impacts (SO_2-eq.)	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.
Toxicity, human	do.	do.	do.	do.
Waste	No Inf.	No Inf.	No Inf.	No Inf.
Other (Eutrophication)	The study concludes that recycling causes **more** impact than landfill.	The study concludes that recycling causes **more** impact than incineration.	The study concludes that recycling causes **more** impact than landfill.	The study concludes that recycling causes **more** impact than incineration.

Study:
06 Kartläggning och utvärdering av plaståtervinning i ett systemperspektiv (Survey and assessmant of plastics recycling from a system perspective)
Study commisioner:
The Swedish Energy Agency (Govermental body)
Comments: FU:

Scenario	Plastic waste from households	Plastic waste from households
Subscenario	Incineration	Incineration
Subscenario no.	6.1	6.2
Material type	HDPE/LDPE	HDPE/LDPE

System boundaries

Material production	*Virgin material*			
	1	Material marginal: Which?	European mix	European mix
	2	Electricity marginal: which?	European mix	European mix
	3	Steam marginal: Which?	No.Inf	European mix
	4	Co-products dealt with?	No	No
	Recovered material			
	5	Material marginal: Which?	No Inf.	No Inf.
	6	Electricity marginal: Which?	Fossil (coal)	Fossil (coal)
	7	Steam marginal: Which?	No Inf.	No Inf.
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	No	No
	10	Type of product dependent material recovery	N.a.	N.a.
Material disposal	11	Disposal comparison	Recycling, ideal (PE partly substitutes wood)	Recycling, realistic (PE partly substitutes wood)
	12	Emissions from landfill included?	No.Inf	No.Inf
	13	Energy from incineration substitutes heat?	Yes*	Yes*
	14	Energy from incineration substitutes electricity?	Yes*	Yes*
	15	Alternative use of incineration capacity incl.?	No.Inf	No.Inf
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:0,7

*both electricity and heat, ratio not specified

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-32%	-19%
Resource consumption	No Inf.	No Inf.
Global warming	-69%	-63%
Saving, [tonne CO_2 eq. / tonne plastics]. A negative value indicates a saving	-1,69	-1,54
Other energy related impacts, SO_2 eq.	-59%	-37%
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other, Eutrophication	-33%	-18%

Study:
07 Smith A, Brown K, Ogilvie S, Rushton K and Bates J, 2001, Waste Management Options and Climate Change.
Study commisioner:
The European Commission
Comments:
Investigates climate change impacts of options for managing MSW

Scenario	Recycling of plastics in Municipal Solid Waste		
Subscenario	Incineration (witout energy recovery)	Incineration (CHP)	Incineration (without energy recovery)
Subscenario no.	7.1	7.2	7.3
Material type	HDPE	HDPE	PET

System boundaries

Material production	*Virgin material*				
	1	Material marginal: Which?	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	No inf.	No inf.	No inf.
	3	Steam marginal: Which?	No inf.	No inf.	No inf.
	4	Co-products dealt with?	No inf.	No inf.	No inf.
	Recovered material				
	5	Material marginal: Which?	EU average	EU average	EU average
	6	Electricity marginal: Which?	No inf.*	No inf.*	No inf.**
	7	Steam marginal: Which?	No inf.*	No inf.*	No inf.**
	8	Co-products dealt with?	No inf.	No inf.	No inf.
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes
	10	Type of product dependent material recovery	Granulate extrusion	Granulate extrusion	Granulate extrusion
Material disposal	11	Disposal comparison	Recycling HDPE Granules	Recycling HDPE Granules	Recycling PET granules
	12	Emissions from landfill included?	Yes	Yes	Yes
	13	Energy from incineration substitutes heat?	No	Yes (average EU generation)	No
	14	Energy from incineration substitutes electricity?	No	Yes (average EU generation)	No
	15	Alternative use of incineration capacity incl.?	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1

* No specification of energy - only reference to Chem Systems (1997):Life Cycle Inventory Development for Recycling. Environm
**No specification of energy - only reference to Buwal (1998): Life Cycle Inventories for Packagings. Environmental Series no. 2

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.	No Inf.
Global warming	No Inf	No Inf	No Inf
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	-2,75	-0,80	-4,02
Other energy related impacts	No Inf.	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.	No Inf.
Waste	No Inf.	No Inf.	No Inf.
Other	No Inf.	No Inf.	No Inf.

Study:
07 Smith A, Brown K, Ogilvie S, Rushton K and Bates J, 2001, Waste Management Options and Climate Change.
Study commisioner:
The European Commission
Comments:
Investigates climate change impacts of options for managing MSW

Scenario	Recycling of plastics in Municipal Solid Waste		
Subscenario	Incineration (CHP)	Landfill	Landfill
Subscenario no.	7.4	7.5	7.6
Material type	PET	HDPE	PET

System boundaries

Material production	*Virgin material*				
	1	Material marginal: Which?	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	No inf.	No inf.	No inf.
	3	Steam marginal: Which?	No inf.	No inf.	No inf.
	4	Co-products dealt with?	No inf.	No inf.	No inf.
	Recovered material				
	5	Material marginal: Which?	EU average	EU average	EU average
	6	Electricity marginal: Which?	No inf.**	No inf.*	No inf.**
	7	Steam marginal: Which?	No inf.**	No inf.*	No inf.**
	8	Co-products dealt with?	No inf.	No inf.	No inf.
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes
	10	Type of product dependent material recovery	Granulate extrusion	Granulate extrusion	Granulate extrusion
Material disposal	11	Disposal comparison	Recycling PET granules	Recycling HDPE Granules	Recycling PET granules
	12	Emissions from landfill included?	Yes	Yes	Yes
	13	Energy from incineration substitutes heat?	Yes (average EU generation)	N.a.	N.a.
	14	Energy from incineration substitutes electricity?	Yes (average EU generation)	N.a.	N.a.
	15	Alternative use of incineration capacity incl.?	No inf.	N.a.	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1

* No specification of energy - only reference to Chem Systems (1997):Life Cycle Inventory Development for Recycling. Environm
**No specification of energy - only reference to Buwal (1998): Life Cycle Inventories for Packagings. Environmental Series no. 2

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.	No Inf.
Global warming	No Inf	No Inf	No Inf
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	-2,07	-0,499	-1,77
Other energy related impacts	No Inf.	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.	No Inf.
Waste	No Inf.	No Inf.	No Inf.
Other	No Inf.	No Inf.	No Inf.

Study:
08 USEPA, 2002, Solid Waste Management And Greenhouse Gases. A Life-Cycle Assessment of Emissions and Sinks
Study commisioner:
United States Environment Protection Agency
Comments:
Development of material-specific GHG emission factors that can be used to account for the climate change benefits of waste management practices. Emissions counted from a Raw Materials Extraction Reference Point

Scenario	Plastics recycling vs. Incineration		
Subscenario	Landfill	Incineration	Landfill
Subscenario no.	8.1	8.2	8.3
Material type	HDPE	HDPE	LDPE

System boundaries

Material production	*Virgin material*				
	1	Material marginal: Which?	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	National average grid mix (including fossil fuels, biomass, hydropower and nuclear power)	National average grid mix (including fossil fuels, biomass, hydropower and nuclear power)	National average grid mix (including fossil fuels, biomass, hydropower and nuclear power)
	3	Steam marginal: Which?	No inf.	No inf.	No inf.
	4	Co-products dealt with?	No	No	No
	Recovered material				
	5	Material marginal: Which?	Average	Average	Average
	6	Electricity marginal: Which?	National average fossil fuel mix	National average fossil fuel mix	National average fossil fuel mix
	7	Steam marginal: Which?	No inf.	No inf.	No inf.
	8	Co-products dealt with?	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling	Recycling	Recycling
	12	Emissions from landfill included?	Yes	Yes	Yes
	13	Energy from incineration substitutes heat?	N.a.	No	No
	14	Energy from incineration substitutes electricity?	N.a.	Yes (National average fossil fuel mix)	Yes (National average fossil fuel mix)
	15	Alternative use of incineration capacity incl.?	N.a.	No	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.	No Inf.
Global warming	-79%	-86%	-76%
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	-1,44	-2,26	-1,75
Other energy related impacts	No Inf.	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.	No Inf.
Waste	No Inf.	No Inf.	No Inf.
Other	No Inf.	No Inf.	No Inf.

Study:

08 USEPA, 2002, Solid Waste Management And Greenhouse Gases. A Life-Cycle Assessment of Emissions and Sinks

Study commisioner:

United States Environment Protection Agency

Comments:

Development of material-specific GHG emission factors that can be used to account for the climate change benefits of waste management practices. Emissions counted from a Raw Materials Extraction Reference Point

Scenario			
Subscenario	Incineration	Landfill	Incineration
Subscenario no.	8.4	8.5	8.6
Material type	LDPE	PET	PET

System boundaries

Material production	*Virgin material*				
	1	Material marginal: Which?	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	National average grid mix (including fossil fuels, biomass, hydropower and nuclear power)	National average grid mix (including fossil fuels, biomass, hydropower and nuclear power)	National average grid mix (including fossil fuels, biomass, hydropower and nuclear power)
	3	Steam marginal: Which?	No inf.	No inf.	No inf.
	4	Co-products dealt with?	No	No	No
	Recovered material				
	5	Material marginal: Which?	Average	Average	Average
	6	Electricity marginal: Which?	National average fossil fuel mix	National average fossil fuel mix	National average fossil fuel mix
	7	Steam marginal: Which?	No inf.	No inf.	No inf.
	8	Co-products dealt with?	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling	Recycling	Recycling
	12	Emissions from landfill included?	Yes	Yes	Yes
	13	Energy from incineration substitutes heat?	No	No	No
	14	Energy from incineration substitutes electricity?	Yes (National average fossil fuel mix)	Yes (National average fossil fuel mix)	Yes (National average fossil fuel mix)
	15	Alternative use of incineration capacity incl.?	No	No	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.	No Inf.
Global warming	-83%	-87%	-92%
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	-2,57	-1,59	-2,59
Other energy related impacts	No Inf.	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.	No Inf.
Waste	No Inf.	No Inf.	No Inf.
Other	No Inf.	No Inf.	No Inf.

Study:

09 Frees N (2002). Environmental advantages and drawbacks by plastic recycling - examples based on specific products (in

Study commisioner:

Danish EPA

Comments:

Scenario	Polyethylene (LDPE) foil	Polypropylene (PP) household packaging waste, low COD	Polypropylene (PP) household packaging waste, medium COD	Polypropylene (PP) household packaging waste, high COD
Subscenario	100 % incineration	100 % incineration	100 % incineration	100 % incineration
Subscenario no.	9.1	9.2	9.3	9.4
Material type	LDPE	PP	PP	PP

System boundaries

Material production	*Virgin material*					
	1	Material marginal: Which?	Average Europe	Average Europe	Average Europe	Average Europe
	2	Electricity marginal: which?	No inf.	No inf.	No inf.	No inf.
	3	Steam marginal: Which?	No inf.	No inf.	No inf.	No inf.
	4	Co-products dealt with?	No	No	No	No
	Recovered material					
	5	Material marginal: Which?	Average Europe	Average Europe	Average Europe	Average Europe
	6	Electricity marginal: Which?	Fossil (natural gas)	Fossil (natural gas)	Fossil (natural gas)	Fossil (natural gas)
	7	Steam marginal: Which?	No inf.	No inf.	No inf.	No inf.
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	washing out contaminats	washing out contaminats	washing out contaminats	washing out contaminats
Material disposal	11	Disposal comparison	100 % recycling	100 % recycling hot water washing	100 % recycling hot water washing	100 % recycling hot water washing
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes
	14	Energy from incineration substitutes electricity?	Yes	Yes	Yes	Yes
	15	Alternative use of incineration capacity incl.?	No	No	No	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-34%	11%	65%	492%
Resource consumption	-58%	-29%	-12%	72%
Global warming	-46%	19%	99%	1675%
Saving, [tonne CO_2 eq. / tonne plastics]	-1,05	0,35	1,28	3,81
Other energy related impacts (SO_2 eq.)	30%	4%	69%	609%
Toxicity; water	No Inf.	No Inf.	No Inf.	No Inf.
Waste	-151%	84%	190%	1255%
Other (eutrophication)	9%	94%	302%	-2350%

Study:
09 Frees N (2001). Environmental advantages and drawbacks by plastic
Study commisioner:
Danish EPA
Comments:

Scenario	Polypropylene (PP) household packaging waste, almost clean	Polypropylene (PP) household packaging waste, low COD	Polypropylene (PP) household packaging waste, medium COD	Polypropylene (PP) household packaging waste, high COD
Subscenario	100 % incineration	100 % incineration	100 % incineration	100 % incineration
Subscenario no.	9.5	9.6	9.7	9.8
Material type	PP	PP	PP	PP

System boundaries

Material production		*Virgin material*				
	1	Material marginal: Which?	Average Europe	Average Europe	Average Europe	Average Europe
	2	Electricity marginal: which?	No inf.	No inf.	No inf.	No inf.
	3	Steam marginal: Which?	No inf.	No inf.	No inf.	No inf.
	4	Co-products dealt with?	No	No	No	No
		Recovered material				
	5	Material marginal: Which?	Average Europe	Average Europe	Average Europe	Average Europe
	6	Electricity marginal: Which?	Fossil (natural gas)	Fossil (natural gas)	Fossil (natural gas)	Fossil (natural gas)
	7	Steam marginal: Which?	Not incl.	Not incl.	Not incl.	Not incl.
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	washing out contaminats	washing out contaminats	washing out contaminats	washing out contaminats
Material disposal	11	Disposal comparison	100 % recycling cold water washing	100 % recycling cold water washing	100 % recycling cold water washing	100 % recycling cold water washing
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes
	14	Energy from incineration substitutes electricity?	Yes	Yes	Yes	Yes
	15	Alternative use of incineration capacity incl.?	No	No	No	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-37%	-24%	21%	281%
Resource consumption	-59%	-54%	-40%	-1%
Global warming	-40%	-23%	40%	1004%
Saving, [tonne CO_2 eq. / tonne plastics]	-0,80	-0,41	0,52	2,28
Other energy related impacts (SO_2 eq.)	-28%	-9%	52%	507%
Toxicity; water	No Inf.	No Inf.	No Inf.	No Inf.
Waste	-11%	14%	98%	716%
Other (eutrophication)	18%	61%	248%	-1954%

Study:

PL104 RDC-Coopers & Lybrand, 1997, Eco-balances for policy-making in the domain of packaging and packaging waste
Study commisioner:
The European Commission
Comments: FU: 1kg of household packaging material

Scenario	Plastic recycling vs energy recovery			
Subscenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario
Subscenario no.	10.1	10.2	10.3	10.4
Material type	PET	PET	PET	PET

System boundaries

Material production	*Virgin material*					
	1	Material marginal: Which?	No inf.	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	3	Steam marginal: fossil or renewable?	No inf.*	No inf.*	No inf.*	No inf.*
	4	Co-products dealt with?	No inf.*	No inf.*	No inf.*	No inf.*
	Recovered material					
	5	Material marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	6	Electricity marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	7	Steam marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Open & closed loop	Open & closed loop	Open & closed loop	Open & closed loop
Material disposal	11	Disposal comparison	Optimistic recycling scenario	Optimistic recycling scenario	Pessimistic recycling scenario	Pessimistic recycling scenario
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes
	14	Energy from incineration substitutes electricity?	Yes	Yes	Yes	Yes
	15	Alternative use of incineration capacity incl.?	No inf.	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1 : 1	1 : 1	1 : 0.5	1 : 0.5

* No specification - only reference to Buwal (1996): Ökoinventare für verpackungen. ** No specification of energy - only reference to RDC

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-42%	-49%	3%	-9%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-45%	-50%	3%	-8%
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	-3.24	-4.11	0.19	-0.68
Other energy related impacts	-41%	-46%	10%	-1%
Toxicity	-59%	22%	-114%	-142%
Waste	-89%	-120%	-239%	159%
Other	-48%	-48%	-18%	-19%

Study:

PL104 RDC-Coopers & Lybrand, 1997, Eco-balances for policy-making in the domain of packaging and packaging waste
Study commisioner:
The European Commission
Comments: FU: 1kg of household packaging material

Scenario	Plastic recycling vs energy recovery			
Subscenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario
Subscenario no.	10.5	10.6	10.7	10.8
Material type	PVC	PVC	PVC	PVC

System boundaries

Material production	*Virgin material*					
	1	Material marginal: Which?	No inf.	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	3	Steam marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	4	Co-products dealt with?	No inf.*	No inf.*	No inf.*	No inf.*
	Recovered material					
	5	Material marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	6	Electricity marginal: Which?	No inf.**	No inf.**	No inf.**	No inf.**
	7	Steam marginal: Which?	No inf.**	No inf.**	No inf.**	No inf.**
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Open & closed loop	Open & closed loop	Open & closed loop	Open & closed loop
Material disposal	11	Disposal comparison	Optimistic recycling scenario	Optimistic recycling scenario	Pessimistic recycling scenario	Pessimistic recycling scenario
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes
	14	Energy from incineration substitutes electricity?	Yes	Yes	Yes	Yes
	15	Alternative use of incineration capacity incl.?	No inf.	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1 : 1	1 : 1	1 : 0.5	1 : 0.5

* No specification - only reference to Buwal (1996): Ökoinventare für verpackungen. ** No specification of energ

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-43%	-52%	7%	-10%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-47%	-50%	-13%	-19%
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	No Inf.	No Inf.	No Inf.	No Inf.
Other energy related impacts	-43%	-52%	18%	0%
Toxicity	-28%	-57%	58%	-5%
Waste	-50%	-50%	-24%	-25%
Other	-49%	-50%	-20%	-22%

The European Commission
Comments: FU: 1kg of household packaging material

Scenario	Plastic recycling vs energy recovery			
Subscenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario
Subscenario no.	10.9	10.10	10.11	10.12
Material type	LDPE	LDPE	LDPE	LDPE

System boundaries

Material production	*Virgin material*					
	1	Material marginal: Which?	No inf.	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	3	Steam marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	4	Co-products dealt with?	No inf.*	No inf.*	No inf.*	No inf.*
	Recovered material					
	5	Material marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	6	Electricity marginal: Which?	No inf.**	No inf.**	No inf.**	No inf.**
	7	Steam marginal: Which?	No inf.**	No inf.**	No inf.**	No inf.**
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Open & closed loop	Open & closed loop	Open & closed loop	Open & closed loop
Material disposal	11	Disposal comparison	Optimistic recycling scenario	Optimistic recycling scenario	Pessimistic recycling scenario	Pessimistic recycling scenario
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes
	14	Energy from incineration substitutes electricity?	Yes	Yes	Yes	Yes
	15	Alternative use of incineration capacity incl.?	No inf.	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1 : 1	1 : 1	1 : 0.5	1 : 0.5

* No specification - only reference to Buwal (1996): Ökoinventare für verpackungen. ** No specification of ene

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-34%	-49%	25%	-4%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-40%	-50%	11%	-7%
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	No Inf.	No Inf.	No Inf.	No Inf.
Other energy related impacts	-29%	-49%	67%	18%
Toxicity	-76%	-51%	-99%	-97%
Waste	-151%	-44%	-300%	116%
Other	-46%	-49%	-5%	-11%

Study:

PL104 RDC-Coopers & Lybrand, 1997, Eco-balances for policy-making in the domain of packaging and packaging waste
Study commisioner:
The European Commission
Comments: FU: 1kg of household packaging material

Scenario	Plastic recycling vs energy recovery			
Subscenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario
Subscenario no.	10.13	10.14	10.15	10.16
Material type	HDPE	HDPE	HDPE	HDPE

System boundaries

Material production	*Virgin material*					
	1	Material marginal: Which?	No inf.	No inf.	No inf.	No inf.
	2	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	3	Steam marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	4	Co-products dealt with?	No inf.*	No inf.*	No inf.*	No inf.*
	Recovered material					
	5	Material marginal: Which?	No inf.*	No inf.*	No inf.*	No inf.*
	6	Electricity marginal: Which?	No inf.**	No inf.**	No inf.**	No inf.**
	7	Steam marginal: Which?	No inf.**	No inf.**	No inf.**	No inf.**
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Open & closed loop	Open & closed loop	Open & closed loop	Open & closed loop
Material disposal	11	Disposal comparison	Optimistic recycling scenario	Optimistic recycling scenario	Pessimistic recycling scenario	Pessimistic recycling scenario
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes
	14	Energy from incineration substitutes electricity?	Yes	Yes	Yes	Yes
	15	Alternative use of incineration capacity incl.?	No inf.	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1 : 1	1 : 1	1 : 0.5	1 : 0.5

* No specification - only reference to Buwal (1996): Ökoinventare für verpackungen. ** No specification

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-33%	-50%	31%	-3%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-40%	-50%	10%	-9%
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	No Inf.	No Inf.	No Inf.	No Inf.
Other energy related impacts	-20%	-49%	92%	23%
Toxicity	-72%	-48%	-92%	-85%
Waste	-130%	-52%	-257%	152%
Other	-46%	-49%	-9%	-13%

Study:

AL-01: Ryberg A., Ekvall T., Person L. and Weidema B. (1998), Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks – Technical Report 3, Danish EPA (Environmental Project no. 402)

Study commisioner:

Danish EPA

Comments:

Part of a comprehensive comparison of packaging materials.

End-of-life options for aluminium cans varied in the course of sensitivity analyses.

Scenario	Packaging systems
Subscenario	Incineration
Subscenario no.	1.1
Material type	Aluminium

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin, European generic
	2	Electricity marginal: which?	Fossil (Coal)
	3	Steam marginal: which?	Fossil (Coal)
	4	Co-products dealt with?	No
	Recovered material		
	5	Material marginal	Virgin, European generic
	6	Electricity marginal: which?	Fossil (Coal)
	7	Steam marginal: which?	Fossil (Coal)
	8	Co-products dealt with?	No
Material recovery	9	Product-dependent material recovery included?	No
	10	Type of product-dependent material recovery	N.a.
Material disposal	11	Disposal comparison	Recycling
	12	Emissions from landfill included?	No
	13	Energy from incineration substitutes heat?	Yes
	14	Energy from incineration substitutes electricity?	Yes
	15	Alternative use of incineration capacity included?	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.
Resource consumption	No Inf.
Global warming	-45%
Saving, [tonnes CO2-eq. / tonne aluminium]	5,42E+00
Other energy related impacts	-77%
Toxicity	No Inf.
Waste	No Inf.
Other, VOC	No Inf.

Values are rounded to nearest multiplum of 1%

Study:

AL-02: Tillman A.-M., Baumann H., Eriksson E. and Rydberg T. (1991). Packaging and the Environment – Life Cycle assessments of packaging materials – calculations of environmental impact (in Swedish)

Study commisioner:

Comments:

1) Emissions from electricity production not included.
2) Electrical energy counted as direct energy, not primary energy.
3) Recycled material may be interpreted as if it displaces 100% primary material, however the recycled material is disposed of by la

Scenario	Aluminium, 100 % virgin			Aluminium, 75 % recycling/25 % virgin
Subscenario	Landfill	Incineration	Landfill	Landfill
Subscenario no.	2.1	2.2	2.3	2.4
Material type	Aluminium	Aluminium	Aluminium	Aluminium

System boundaries

Material production		*Virgin material*				
	1	Material marginal	Average Schweiz	Average Schweiz	Average Schweiz	Average Schweiz
	2	Electricity marginal: which?	Not incl.	Not incl.	Not incl.	Not incl.
	3	Steam marginal: which?	Not incl.	Not incl.	Not incl.	Not incl.
	4	Co-products dealt with?	No	No	No	No
		Recovered material				
	5	Material marginal	Average Sweden	Average Sweden	Average Sweden	Average Sweden
	6	Electricity marginal: which?	Not incl.	Not incl.	Not incl.	Not incl.
	7	Steam marginal: which?	Not incl.	Not incl.	Not incl.	Not incl.
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product-dependent material recovery included?	No	No	No	No
	10	Type of product-dependent material recovery	-	-	-	-
Materi	11	Disposal comparison	Recycling	Recycling	Incineration	Incineration
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	No	No	No	No
	14	Energy from incineration substitutes electricity?	No	No	No	No
	15	Alternative use of incineration capacity included?	No	No	No	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No Inf.	No Inf.	No Inf.	No Inf.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-80%	-80%	-20%	-20%
Resource consumption	-100%	-60%	-80%	-60%
Global warming	-100%	-80%	-60%	-40%
Saving, [kg CO2-eq. / tonne aluminium]	4029,30	1837,30	2192,00	548,00
Other energy related impacts	-100%	-100%	-20%	-20%
Toxicity	No Inf.	No Inf.	No Inf.	No Inf.
Waste	No Inf.	No Inf.	No Inf.	No Inf.
Other	No Inf.	No Inf.	No Inf.	No Inf.

Values are rounded to nearest multiplum of 20%

Study:
AL-03: US-EPA, 2002, Solid Waste Management And Greenhouse Gases. A Life-Cycle Assessment of Emissions and Sinks
Study commisioner:
United States Environment Protection Agency
Comments:

Development of material-specific GHG emission factors that can be used to account for the climate change benefits of waste management practices. Emissions counted from a Raw Materials Extraction Reference Point

Scenario	Aluminium recycling	
Subscenario	Landfill	Incineration
Subscenario no.	3.1	3.2
Material type	Aluminium cans	Aluminium cans

System boundaries

Material production	*Virgin material*			
	1	Material marginal	Virgin aluminium (US average)	Virgin aluminium (US average)
	2	Electricity marginal: which?	US average fossil fuel mix	US average fossil fuel mix
	3	Steam marginal: which?	No inf.	No inf.
	4	Co-products dealt with?	No	No
	Recovered material			
	5	Material marginal	US average conditions	US average conditions
	6	Electricity marginal: which?	US average grid mix (including fossil fuels, biomass, hydropower and nuclear power)	US average grid mix (including fossil fuels, biomass, hydropower and nuclear power)
	7	Steam marginal: which?	No inf.	N.a.
	8	Co-products dealt with?	No	N.a.
Material recovery	9	Product-dependent material recovery included?	Yes	N.a.
	10	Type of product-dependent material recovery	Closed loop	N.a.
Material disposal	11	Disposal comparison	Landfill	Incineration
	12	Emissions from landfill included?	Yes	Yes
	13	Energy from incineration substitutes heat?	N.a.	No
	14	Energy from incineration substitutes electricity?	N.a.	Yes (National average fossil fuel mix)
	15	Alternative use of incineration capacity included?	N.a.	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:0.93	1:0.93

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than incineration.
Saving, [tonne CO2 eq. / tonne aluminium]	15.10	15.13
Other energy related impacts	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Study:

AL-04: RDC-Coopers & Lybrand, 1997, Eco-balances for policy-making in the domain of packaging and packaging waste

Study commisioner:

The European Commission

Comments: FU: 1kg of household packaging material

Scenario	Aluminium recycling vs. energy recovery (via incineration)			
Subscenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario
Subscenario no.	4.1	4.2	4.3	4.4
Material type	Aluminium	Aluminium	Aluminium	Aluminium

System boundaries

Material production	*Virgin material*					
	1	Material marginal	Primary aluminium, unspecified origin	Primary aluminium, unspecified origin	Primary aluminium, unspecified origin	Primary aluminium, unspecified origin
	2	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	3	Steam marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	4	Co-products dealt with?	No	No	No	No
	Recovered material					
	5	Material marginal	Aluminium packaging scrap from households	Aluminium packaging scrap from households	Aluminium packaging scrap from households	Aluminium packaging scrap from households
	6	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	7	Steam marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product-dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product-dependent material recovery	Closed loop	Closed loop	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Optimistic energy recovery scenario	Pessimistic energy recovery scenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	No inf.**	No inf.**	No inf.**	No inf.**
	14	Energy from incineration substitutes electricity?	No inf.**	No inf.**	No inf.**	No inf.**
	15	Alternative use of incineration capacity included?	No inf.	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1

* No specification of energy - only reference to Buwal (1996): Ökoinventare für verpackungen. **No specific information on substitution, however, energy production and application rate is included

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-32%	-70%	35%	-40%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.
Global warming	-35%	-72%	36%	-41%
Saving, [tonne CO2 eq. / tonne aluminium]	2,75	13,16	-2,87	7,54
Other energy related impacts	-33%	-72%	51%	-37%
Toxicity	-36%	-73%	31%	-44%
Waste	-46%	-82%	55%	-48%
Other (photochemical Oxidant Formation and Ozone Layer depletion)	-31%	-71%	56%	-35%

Study:

AL-05: Grant et al (2001) LCA for paper and packaging waste management scenarios in Victoria

Study commisioner:

EcoRecycle Victoria, Australia

Comments:

Decision to support: evaluate the environmental performance of aluminium packaging recycling vs. landfilling (no scenario with incineration). FU: management of the recyclable fraction of aluminium packaging from the average Melbourne household in one week

Scenario	Aluminium Packaging recycling, 52.9%
Subscenario	Landfill
Subscenario no.	5.1
Material type	Aluminium

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin aluminium in KAAL, Yennora NSW, Australia
	2	Electricity marginal: which?	Average in SE Australia: 52.6% coal, 35.9% brown coal, 6.3% nat.gas, 5.2% hydro, 0.0003% wind, 0.0193% Oil
	3	Steam marginal: which?	No inf.
	4	Co-products dealt with?	No
	Recovered material		
	5	Material marginal	Virgin aluminium in KAAL, Yennora NSW, Australia
	6	Electricity marginal: which?	Average in SE Australia: 52.6% coal, 35.9% brown coal, 6.3% nat.gas, 5.2% hydro, 0.0003% wind, 0.0193% Oil
	7	Steam marginal: which?	No inf.
	8	Co-products dealt with?	No
Material recovery	9	Product-dependent material recovery included?	Yes
	10	Type of product-dependent material recovery	Recycling plant for packaging aluminium remelting
Material disposal	11	Disposal comparison	Recycling (52.9%,rest to landfilling) vs. 100% landfilling
	12	Emissions from landfill included?	Yes
	13	Energy from incineration substitutes heat?	N.a.
	14	Energy from incineration substitutes electricity?	N.a.
	15	Alternative use of incineration capacity included?	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:0.9025 (1 kg aluminium per 0.9025 kg aluminium scrap)

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy		-87%
Resource co	water	No Inf.
Global warming		-87%
Saving, [tonne CO2 eq. / tonne aluminium]		0,44
Other energy related impacts		No Inf.
Toxicity		No Inf.
Waste		-89%
Other	smog precursors	-93%

Values are rounded up (or down) to nearest multiplum of 1%

Study:

AL-06: RDC-Pira, 2003, Evaluation of costs and benefits for the achievement of reuse and recycling targets for the different packaging materials in the frame of the packaging and packaging waste directive 94/62/EC

Study commisioner:

The European Commission

Comments:

Values for comparison of waste management options have been extracted through own calculations based on data in annex 10

Scenario	Recycling of aluminium cans in Municipal Solid Waste (kerbsite collection in low population density areas)	
Subscenario	Landfill	Incineration
Subscenario no.	6.1	6.2
Material type	Aluminium cans	Aluminium cans

System boundaries

Material production	*Virgin material*			
	1	Material marginal	Virgin aluminium, unspecified origin	Virgin aluminium, unspecified origin
	2	Electricity marginal: which?	No inf.*	No inf.*
	3	Steam marginal: which?	No inf.*	No inf.*
	4	Co-products dealt with?	No	No
	Recovered material			
	5	Material marginal	Aluminium cans from households	Aluminium cans from households
	6	Electricity marginal: which?	No inf.*	No inf.*
	7	Steam marginal: which?	No inf.*	No inf.*
	8	Co-products dealt with?	No	No
Material recovery	9	Product-dependent material recovery included?	Yes	Yes
	10	Type of product-dependent material recovery	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Landfill	Incineration
	12	Emissions from landfill included?	Yes	N.a.
	13	Energy from incineration substitutes heat?	N.a.	Yes
	14	Energy from incineration substitutes electricity?	N.a.	Yes
	15	Alternative use of incineration capacity included?	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.	No inf.

* Details not directly available. Data in report is derived from: 'Environmental Profile Report for the European Aluminium Industry', European Aluminium Association, April 2000

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than Incineration.
Saving, [tonne CO2 eq. / tonne aluminium]	9.33	9.38
Other energy related impacts	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than Incineration.
Toxicity	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than Incineration.
Waste	The study concludes that recycling causes less impact than landfill.	The study concludes that recycling causes less impact than Incineration.
Other	No Inf.	No Inf.

Study:

AL-07: Smith A., Brown K., Ogilvie S., Rushton K. and Bates J., 2001, Waste Management Options and Climate Change

Study commisioner:

The European Commission

Comments:

Investigates climate change impacts of options for managing Municipal Solid Waste

Scenario	Recycling of aluminium in Municipal Solid Waste
Subscenario	Landfill
Subscenario no.	7.1
Material type	

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin aluminium ingot
	2	Electricity marginal: which?	No inf.*
	3	Steam marginal: which?	No inf.*
	4	Co-products dealt with?	No
	Recovered material		
	5	Material marginal	Recycled aluminum ingot
	6	Electricity marginal: which?	No inf.*
	7	Steam marginal: which?	No inf.*
	8	Co-products dealt with?	No
Material recovery	9	Product-dependent material recovery included?	Yes
	10	Type of product-dependent material recovery	Closed loop
Material disposal	11	Disposal comparison	Landfill
	12	Emissions from landfill included?	Yes
	13	Energy from incineration substitutes heat?	N.a.
	14	Energy from incineration substitutes electricity?	N.a.
	15	Alternative use of incineration capacity included?	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.

* No specification of energy - only reference to Buwal (1998): Life Cycle Inventoties for Packagings. Environmental Series no. 250

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.
Resource consumption	No Inf.
Global warming, CO_2 eq.	The study concludes that recycling causes less impact than landfill.
Saving, [tonne CO2 eq. / tonne aluminium]	9,08
Other energy related impacts	No Inf.
Toxicity	No Inf.
Waste	No Inf.
Other	No Inf.

Study:

AL-08: Pommer, K.; Wesnaes, M.S. and Madsen, C. (1995): Environmental Survey of Packaging Systems for Beer and Soft Drinks (in Danish), Sub Report 3, Danish EPA (Work Report no. 72)

Study commisioner:

Danish EPA

Comments:

The purpose is to compare materials for packaging

Scenario	Packaging systems
Subscenario	Incineration
Subscenario no.	8.1
Material type	Aluminium

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Global generic
	2	Electricity marginal: which?	Fossil and nuclear
	3	Steam marginal: which?	Fossil and nuclear
	4	Co-products dealt with?	No
	Recovered material		
	5	Material marginal	Global generic
	6	Electricity marginal: which?	Fossil and nuclear
	7	Steam marginal: which?	Fossil and nuclear
	8	Co-products dealt with?	No
Material recovery	9	Product-dependent material recovery included?	No
	10	Type of product-dependent material recovery	N.a.
Material disposal	11	Disposal comparison	Recycling
	12	Emissions from landfill included?	N.a.
	13	Energy from incineration substitutes heat?	Yes
	14	Energy from incineration substitutes electricity?	Yes
	15	Alternative use of incineration capacity included?	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-56%
Resource consumption	No Inf.
Global warming	No Inf.
Saving, [tonne CO2 eq. / tonne aluminium]	No Inf.
Other energy related impacts	No Inf.
Toxicity	No Inf.
Waste	No Inf.
Other, VOC	No Inf.

Values are rounded up (or down) to nearest multiplum of 1%

Study:
AL-09: Edwards, D.W.; Schelling, J. (1996), Municipal Waste Life Cycle Assessment
Study commisioner:
N.a
Comments:
Issue addressed: Savings due to recycling, compared to incineration and to landfill

Scenario	Recycling	Recycling
Subscenario	Incineration	Landfill
Subscenario no.	9.1	9.2
Material type	Aluminium	Aluminium

System boundaries

Material production	*Virgin material*			
	1	Material marginal	No inf.	No inf.
	2	Electricity marginal: which?	Global Al average	Global Al average
	3	Steam marginal: which?	Not incl.	Not incl.
	4	Co-products dealt with?	No	No
	Recovered material			
	5	Material marginal	No inf.	No inf.
	6	Electricity marginal: which?	UK average	UK average
	7	Steam marginal: which?	Not incl.	Not incl.
	8	Co-products dealt with?	No	No
Material recovery	9	Product-dependent material recovery included?	No	No
	10	Type of product-dependent material recovery	N.a.	N.a.
Material disposal	11	Disposal comparison	Recycling	Recycling
	12	Emissions from landfill included?	N.a.	Yes, but estimated zero
	13	Energy from incineration substitutes heat?	No (In fact, a negative heating value is estimated as Al absorbs heat generated in the incinerator)	N.a.
	14	Energy from incineration substitutes electricity?	No	N.a.
	15	Alternative use of incineration capacity included?	No (not in calculations, but discussed)	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	The study concludes that recycling causes less impact than incineration.	The study concludes that recycling causes less impact than landfill.
Saving, [tonne CO_2 eq. / tonne aluminium]	9,9707	9,9219
Other energy related impacts	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Study:

AL-10: Schonert, M. et al. (2002), Ecobalance for beverage packaging - UBA II (in German), (2 reports + 1 update report)

Study commisioner:

German EPA

Comments:

Comparison of 28 existing packaging systems in Germany. Main materials: glass, PET, aluminium, steel, composite carton. (Other materials: HDPE, wood, PP, PVC, corrugated cardboard)

Scenario	Packaging systems
Subscenario	75% recycling (25% incineration & landfill)
Subscenario no.	10.1
Material type	Aluminium

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Global average
	2	Electricity marginal: which?	Average (Al production mix [EU & global])
	3	Steam marginal: which?	Average
	4	Co-products dealt with?	No
	Recovered material		
	5	Material marginal	German average
	6	Electricity marginal: which?	Average (German mix for secondary aluminium)
	7	Steam marginal: which?	Average
	8	Co-products dealt with?	No
Material recovery	9	Product-dependent material recovery included?	Yes
	10	Type of product-dependent material recovery	Detailed model for throw-away cans
Material disposal	11	Disposal comparison	NONE (only 1 average disposal scenario)
	12	Emissions from landfill included?	Yes
	13	Energy from incineration substitutes heat?	Yes
	14	Energy from incineration substitutes electricity?	Yes
	15	Alternative use of incineration capacity included?	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.
Resource consumption	No Inf.
Global warming	The study concludes that recycling causes less impact than landfill or incineration.
Saving, [tonne CO2 eq. / tonne aluminium]	No Inf.
Other energy related impacts	No Inf.
Toxicity	No Inf.
Waste	No Inf.
Other, VOC	No Inf.

Study:

AL-11: Craighill and Powell (1996), Lifecycle assessment and economic evaluation of recycling: a case study
Study commisioner:
EcoRecycle Victoria, Australia
Comments:
Decision to support: Evaluate the environmental performance of 1kg aluminium in waste in Milton Keynes, UK, in a recycling scenario vs. landfilling (no scenario with incineration). FU: Management of 1 kg of aluminium in waste.

Scenario	Aluminium Packaging in waste
Subscenario	Landfill
Subscenario no.	11.1
Material type	Aluminium

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin aluminium, no specific origin specified
	2	Electricity marginal: which?	Average mix in UK, 1995 (not specified)
	3	Steam marginal: which?	No inf.
	4	Co-products dealt with?	No
	Recovered material		
	5	Material marginal	Other secondary aluminium in Germany, no specific origin or composition specified
	6	Electricity marginal: which?	Average mix in UK, 1995 (not specified)
	7	Steam marginal: which?	No inf.
	8	Co-products dealt with?	No materials. Energy saving of 77% by using recycled material instead of virgin material
Material recovery	9	Product-dependent material recovery included?	No inf.
	10	Type of product-dependent material recovery	No inf.
Material disposal	11	Disposal comparison	Recycling (2.5% residuals to landfilling)
	12	Emissions from landfill included?	To air: Yes (but not applicable to aluminium)To water: No info.
	13	Energy from incineration substitutes heat?	N.a.
	14	Energy from incineration substitutes electricity?	N.a.
	15	Alternative use of incineration capacity included?	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.
Resource consumption	No Inf.
Global warming	-95%
Saving, [tonne CO2 eq. / tonne aluminium]	50,35
Other energy related impacts, nutrient enrichment / acidification	-94%
Toxicity	No Inf.
Waste	No Inf.
Other CO2	-95%

Values are rounded up (or down) to nearest multiplum of 1%

Study:
ST-1 Craighill and Powell (1996) Lifecycle assessment and economic evaluation of recycling: a case study.

Study commisioner:
CSERGE, UK
Comments:
Decision to support: evaluate the environmental performance of 1kg steel in waste in Milton Keynes, UK, in a recycling scenario vs. landfilling (no scenario with incineration)

FU: management of 1 kg of steel in waste.

Scenario	Steel Packaging in waste, max. recycling (landfilling of 2.5%residuals) vs 100% landfilling
Subscenario	N.a
Subscenario no.	ST-1.1
Material type	Steel packaging

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin steel, unspecified origin
	2	Electricity marginal: which?	Average mix in UK, 1995 (not specified)
	3	Steam marginal: which?	No inf.
	4	Co-products dealt with?	No
	Secondary material		
	5	Material marginal	Other secondary steel in Hartlepool, UK, unspecified origin or composition
	6	Electricity marginal: which?	Average mix in UK, 1995 (not specified)
	7	Steam marginal: which?	No inf.
	8	Co-products dealt with?	No materials. Energy saving of 77% by using recycled material instead of virgin material
Material recovery	9	Product dependent material recovery included?	No inf.
	10	Type of product dependent material recovery	No inf.
Material disposal	11	Disposal comparison	Recycling (2.5% residuals to landfilling) vs. 100% landfilling
	12	Emissions from landfill included?	To air: Yes (but not applicable to steel)To water: No info.
	13	Energy from incineration substitutes heat?	N.a.
	14	Energy from incineration substitutes electricity?	N.a.
	15	Alternative use of incineration capacity included?	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.
Resource consumption	No Inf.
Global warming	-5%
Saving, [tonne CO2 eq. / tonne steel]	0,01
Other energy nutrient enrichment	18%
Acidification	-26%
Toxicity	No Inf.
Waste	No Inf.
Other	

Values are rounded up (or down) to nearest multiplum of 1%

Study:

ST-2 Tillman A-M, Baumann H, Eriksson E and Rydberg T (1991). Packaging and the Environment – Life Cycle assessments of packaging materials – calculations of environmental impact (in Swedish)

Study commisioner:

Swedish commission on Packaging

Comments:

1) Emissions from electricity production not included.
2) Electrical energy counted separately as direct energy, not primary energy.
3) Recycled material may be interpreted as if it substitutes 100 % primary material.
4) Comparison of 70% recycling /30% landfilling vs. 100% landfill assumed to be a 100% vs 100% comparison, after verification that the error of this assumption is < 10%

Scenario			70% recycling of steel plate	70% recycling of tin-steel plate
Subscenario				
Subscenario no.			ST-2.1	ST-2.2
Material type			steel	tin plate
System boundaries				
Material production	*Virgin material*			
	1	Material marginal	Swedish steel production	Swedish steel production, tin process in Germany/France
	2	Electricity marginal: which?	Swedish average : 49% hydro, 45% nuclear, 6% fossil	Swedish average : 49% hydro, 45% nuclear, 6% fossil
	3	Steam marginal: fossil or renewable?	No inf.	No inf.
	4	Any co-products accounted for?	No inf.	No inf.
	Recovered material			
	5	Material marginal	No inf.	No inf.
	6	Electricity marginal: fossil or renewable?	non-fossil energy	non-fossil energy
	7	Steam marginal: fossil or renewable?	No inf.	No inf.
	8	Any co-products accounted for?	No inf.	No inf.
Material recovery	9	Product dependent material recovery included?	Yes	No
	10	Type of product dependent material recovery	Other packaging scrap from swedish packaging is substituted	Other packaging scrap from swedish packaging is substituted
Mater	11	Disposal comparison	70% Recycling, 30% Landfilling vs. 100% Landfilling	70% Recycling, 30% Landfilling vs. 100% Landfilling
	12	Emissions from landfill included?	No	No
	13	Energy from incineration substitutes heat?	Yes. But not applicable here.	Yes. But not applicable here.
	14	Energy from incineration substitutes electricity?	Yes. But not applicable here.	Yes. But not applicable here.
	15	Alternative use of incineration capacity incl.?	Yes. Landfill	Yes. Landfill
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No Inf.	No Inf.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	power	1%	6%
	heat	-44%	-39%
Total primary energy		-28%	-23%
Resource consumption		No Inf.	No Inf.
Global warm	CO2	-47%	-43%
Saving, [tonne CO2 eq. / tonne steel]		1,04	1,04
Other energ	NOx	-29%	-20%
	SO2	-51%	-49%
Toxicity	oil	-40%	-35%
	phenol	-17%	-17%
	COD	-15%	-11%
Waste	ashes	-58%	-57%

Study:

ST-3 Grant et al (2001) LCA for paper and packaging waste management scenarios in Victoria

Study commisioner:

EcoRecycle Victoria, Australia

Comments:

Decision to support: evaluate the environmental performance of steel packaging recycling vs. landfilling (no scenario with incineration)

FU: management of the recyclable fraction of steel packaging from the average Melbourne household in one week (0.17kg steel/FU).

Scenario	Steel Packaging recycling, 37.05%
Subscenario	N.a
Subscenario no.	ST-3.1
Material type	Steel-Tin plate

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Pig iron manufactured in Basic Oxygen Steel Furnace in Port Kambala, Australia
	2	Electricity marginal: which?	Average in SE Australia: 52.6% coal, 35.9% brown coal, 6.3% nat.gas, 5.2% hydro, 0.0003% wind, 0.0193% Oil
	3	Steam marginal: which?	No inf.
	4	Co-products dealt with?	No. (not available at the moment of publication)
	Secondary material		
	5	Material marginal	Other scrap used in Basic Oxygen Steel Furnace in Port Kambala, Australia
	6	Electricity marginal: which?	Average in SE Australia: 52.6% coal, 35.9% brown coal, 6.3% nat.gas, 5.2% hydro, 0.0003% wind, 0.0193% Oil
	7	Steam marginal: which?	No inf.
	8	Co-products dealt with?	No: (not available at the moment of publication)
Material recovery	9	Product dependent material recovery included?	Yes
	10	Type of product dependent material recovery	De-tinning of 25% of the steel-tin plates. Sludge sent to Malaysia. Other residues of de-tinning regenerated in other Australian facilities
Material disposal	11	Disposal comparison	Recycling (37.05%,rest to landfilling) vs. 100% landfilling
	12	Emissions from landfill included?	Yes
	13	Energy from incineration substitutes heat?	Yes, but not applicable to this material
	14	Energy from incineration substitutes electricity?	Yes, but not applicable to this material
	15	Alternative use of incineration capacity included?	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:0.91 (losses from de-tinning, since tin removal is necessary to keep the steel quality)

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy		-70%
Resource coı	water	No Inf.
Global warming		-71%
Saving, [tonne CO2 eq. / tonne steel]		2,97
Other energy related impacts		No Inf.
Toxicity		No Inf.
Waste		-95%
Other	smog precursors	-71%

Values are rounded up (or down) to nearest multiplum of 1%

Study:

ST-4 Muñoz et al. (2004), LCA application to integrated waste management planning in Gipuzkoa (Spain). Int. J. of LCA 9(4) 272-280. Background report: LCA applied to different alternatives for the management of MSW and sewage sludge in the waste managemen

Study commisioner:

Diputación Foral de Gipuzkoa (Regional Government of Gipuzkoa)

Comments:

The purpose is to compare alternatives for the handling of MSW generated in 2016

Scenario	Steel waste collection and recycling
Subscenario	
Subscenario no.	ST-4.1
Material type	Steel from municipal waste - no specified quality

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin steel, unspecified origin
	2	Electricity marginal: which?	Prediction of marginal supply mix in 2016: 70% hydro, 20% coal, 5% nat.gas, 5% other
	3	Steam marginal: which?	Fossil (natural gas)
	4	Co-products dealt with?	No
	Secondary material		
	5	Material marginal	Steel scrap, unspecified. (1)
	6	Electricity marginal: which?	Prediction of marginal supply mix in 2016: 70% hydro, 20% coal, 5% nat.gas, 5% other
	7	Steam marginal: which?	Fossil (natural gas)
	8	Co-products dealt with?	No
Material recovery	9	Product dependent material recovery included?	No inf.
	10	Type of product dependent material recovery	No inf.
Material disposal	11	Disposal comparison	100% Recycling vs. 100% landfilling
	12	Emissions from landfill included?	Yes. Not applicable to this material.
	13	Energy from incineration substitutes heat?	Yes. But not applicable to this material.
	14	Energy from incineration substitutes electricity?	Yes. But not applicable to this material.
	15	Alternative use of incineration capacity included?	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:0.95

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy		-100%
Resource coı	Water consumption	-94%
Global warming		-98%
Saving, [tonne CO2 eq. / tonne steel]		1,073538
Other energy	Acidification	-95%
	Eutrophization	-88%
	Photochemical oxidant formation	-100%
Toxicity	Human toxicity	-93%
Waste		-100%
Other, VOC	Ozone depletion	-49%

(1) From Bergh and Jurgens database

Values are rounded up (or down) to nearest multiplum of 1%

Study:

ST-5 Pommer, K.; Wesnaes, M.S. (1995), Environmental description (kortlægning) of Packaging Systems for Beer and Soft Drinks (in Danish), Main report, Danish EPA (Work Report no. 72)

Study commisioner:

Danish EPA

Comments:

The purpose is to compare materials for packaging

Scenario	Packaging systems
Subscenario	Incineration
Subscenario no.	ST-5.1
Material type	Steel tinplate

System boundaries

Material production	*Virgin material*		
	1	Material marginal	Virgin steel, Central European average
	2	Electricity marginal: which?	Fossil (Coal)
	3	Steam marginal: fossil or renewable?	Fossil (Coal)
	4	Any co-products accounted for?	No
	Recovered material		
	5	Material marginal	Steel scrap, Central European average to Electric Arc Furnaces
	6	Electricity marginal: fossil or renewable?	Fossil (Coal)
	7	Steam marginal: fossil or renewable?	Fossil (Coal)
	8	Any co-products accounted for?	No
Material recovery	9	Product dependent material recovery included?	No
	10	Type of product dependent material recovery	N.a.
Material disposal	11	Disposal comparison	100% Recycling vs. 100% incineration followed by slag landfilling
	12	Emissions from landfill included?	Not included. Assumed of little magnitude
	13	Energy from incineration substitutes heat?	Not applicable
	14	Energy from incineration substitutes electricity?	Not applicable
	15	Alternative use of incineration capacity incl.?	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf. Material loss during manufacture of steel from scrap: 15%

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-45%
Resource consumption	No Inf.
Global warming	No Inf.
Saving, [tonne CO2 eq. / tonne steel]	0,793
Other energy related impacts	No Inf.
Toxicity	No Inf.
Waste	No Inf.
Other, VOC	No Inf.

Study:

ST-6 USEPA, 2002, Solid Waste Management And Greenhouse Gases. A Life-Cycle Assessment of Emissions and Sinks

Study commisioner:

United States Environment Protection Agency

Comments:

Development of material-specific GHG emission factors that can be used to account for the climate change benefits of waste management practices. Emissions counted from a Raw Materials Extraction Reference Point

Scenario			Steel recycling vs. Incineration	
Subscenario			Landfill	Incineration
Subscenario no.			ST-6.1	ST-6.2
Material type			Steel cans	Steel cans
System boundaries				
Material production	*Virgin material*			
	1	Material marginal	Virgin steel (US average)	Virgin steel (US average)
	2	Electricity marginal: which?	US average fossil fuel mix	US average fossil fuel mix
	3	Steam marginal: which?	No inf.	No inf.
	4	Co-products dealt with?	No	No
	Secondary material			
	5	Material marginal	US average conditions	US average conditions
	6	Electricity marginal: which?	US average grid mix (including fossil fuels, biomass, hydropower and nuclear power)	US average grid mix (including fossil fuels, biomass, hydropower and nuclear power)
	7	Steam marginal: which?	No inf.	No inf.
	8	Co-products dealt with?	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling	Recycling
	12	Emissions from landfill included?	Yes	Yes
	13	Energy from incineration substitutes heat?	N.a.	No
	14	Energy from incineration substitutes electricity?	N.a.	Yes (National average fossil fuel mix)
	15	Alternative use of incineration capacity included?	N.a.	No
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:0.93	1:0.93

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	-63%	-19%
Saving (tonne CO2-eq/tonne steel)	1,83	0,26
Other energy related impacts	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Values are rounded up (or down) to nearest multiplum of 1%

Study:

ST-7 Smith A, Brown K, Ogilvie S, Rushton K and Bates J, 2001, Waste Management Options and Climate Change.
Study commisioner:
The European Commission
Comments:
Investigates climate change impacts of options for managing MSW

Scenario	Recycling of ferrous metals in MSW	
Subscenario	Incineration (Fe metal recovered from bottom ash)	Landfill
Subscenario no.	ST-7.1	ST-7.2
Material type		

System boundaries

Material production	*Virgin material*			
	1	Material marginal	Not incl.	Not incl.
	2	Electricity marginal: which?	Not incl.	Not incl.
	3	Steam marginal: fossil or renewable?	Not incl.	Not incl.
	4	Any co-products accounted for?	Not incl.	Not incl.
	Recovered material			
	5	Material marginal	Tin plate from non-detinned scrap	Tin plate from non-detinned scrap
	6	Electricity marginal: fossil or renewable?	No inf.*	No inf.*
	7	Steam marginal: fossil or renewable?	No inf.*	No inf.*
	8	Any co-products accounted for?	No inf.	No inf.
Material recovery	9	Product dependent material recovery included?	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling in tin plate manufacturing	Recycling in tin plate manufacturing
	12	Emissions from landfill included?	Yes	Yes
	13	Energy from incineration substitutes heat?	Yes (average EU generation)	N.a.
	14	Energy from incineration substitutes electricity?	Yes (average EU generation)	N.a.
	15	Alternative use of incineration capacity incl.?	No inf.	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.	No inf.

* No specification of energy - only reference to Buwal (1998): Life Cycle Inventoties for Packagings. Environmental Serie

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	10%	-98%
savings (tonnes CO2-eq/tonne steel)	-0,14	1,53
Other energy related impacts	No Inf.	No Inf.
Toxicity	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Values are rounded up (or down) to nearest multiplum of 1%

Study:

ST-8 RDC-Coopers & Lybrand, 1997, Eco-balances for policy-making in the domain of packaging and packaging waste

Study commisioner:

The European Commission

Comments: FU: 1kg of household packaging material

Scenario	Steel recycling vs energy recovery			
Subscenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario	Optimistic energy recovery scenario	Pessimistic energy recovery scenario
Subscenario no.	ST-8.1	ST-8.2	ST-8.3	ST-8.4
Material type	Steel packaging	Steel packaging	Steel packaging	Steel packaging

System boundaries

Material production	*Virgin material*					
	1	Material marginal	Primary steel (containing 12% recycled material)	Primary steel (containing 12% recycled material)	Primary steel (containing 12% recycled material)	Primary steel (containing 12% recycled material)
	2	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	3	Steam marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	4	Co-products dealt with?	No	No	No	No
	Secondary material					
	5	Material marginal	Steel packaging scrap from households	Steel packaging scrap from households	Steel packaging scrap from households	Steel packaging scrap from households
	6	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	7	Steam marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Optimistic recycling scenario	Optimistic recycling scenario	Pessimistic recycling scenario	Pessimistic recycling scenario
	12	Emissions from landfill included?	No	No	No	No
	13	Energy from incineration substitutes heat?	Yes	Yes	Yes	Yes
	14	Energy from incineration substitutes electricity?	Yes	Yes	Yes	Yes
	15	Alternative use of incineration capacity included?	No inf.	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1	1:1	1:1

* No specification - only reference to Buwal (1996): Ökoinventare für verpackungen.

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	0%	-41%	48%	-12%
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.
GWP	-3%	-48%	52%	-18%
Energy related impacts, other (1)	7%	-39%	93%	10%
Savings (tonne CO2-eq/tonne steel)	0,11	3,09	(1,81)	1,17
Toxicity (human and eco)	-8%	-66%	76%	-34%
Waste (2)	0%	-2%	1%	-1%
Other (3)	12%	-46%	184%	38%

(1) Acidificaton and nutrification (2) harzardous, municipal, inert, mining and radioactive

(3) photochemical Oxidant Formation and Ozone Layer depletion

Values are rounded up (or down) to nearest multiplum of 1%

Study:

ST-9 RDC-Pira, 2003, Evaluation of costs and benefits for the achievement of reuse and recycling targets for the different packaging materials in the frame of the packaging and packaging waste directive 94/62/EC

Study commisioner:

The European Commission

Comments:

Values for comparison of waste management options have been extracted through own calculations based on data in annex 10

Scenario	Recycling of steel cans in MSW (kerbsite collection in low population density areas)					
Subscenario	Landfill vs. Recycling (kerbside)	Incineration vs. recycling (kerbside)	Incineration (incl. 80% recovery of steel from slag)	Landfill vs. Recycling (bring scheme)	Incineration vs. recycling (bring scheme)	Incineration (incl. 80% recovery of steel from slag)
Subscenario no.	ST-9.1	ST-9.2	ST-9.3	ST-9.4	ST-9.5	ST-9.6
Material type	Steel packaging	Steel packaging	Steel packaging	Steel packaging	Steel packaging	Steel packaging

System boundaries

Material production		*Virgin material*						
	1	Material marginal	Virgin steel, unspecified origin	Virgin steel, unspecified origin	Virgin steel, unspecified origin	Virgin steel, unspecified origin	Virgin steel, unspecified origin	Virgin steel, unspecified origin
	2	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*	No inf.*	No inf.*
	3	Steam marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*	No inf.*	No inf.*
	4	Co-products dealt with?	No	No	No	No	No	No
		Secondary material						
	5	Material marginal	Steel scrap to electric arc furnace	Steel scrap to electric arc furnace	Steel scrap to electric arc furnace	Steel scrap to electric arc furnace	Steel scrap to electric arc furnace	Steel scrap to electric arc furnace
	6	Electricity marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*	No inf.*	No inf.*
	7	Steam marginal: which?	No inf.*	No inf.*	No inf.*	No inf.*	No inf.*	No inf.*
	8	Co-products dealt with?	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
Mat. recovery	9	Product dependent material recovery included?	Yes	Yes	Yes	Yes	Yes	Yes
	10	Type of product dependent material recovery	Closed loop	Closed loop	Closed loop	Closed loop	Closed loop	Closed loop
Material disposal	11	Disposal comparison	Recycling with kerside collection	Recycling with kerside collection	Recycling with kerside collection	Recycling with bring scheme	Recycling with bring scheme	Recycling with bring scheme
	12	Emissions from landfill included?	Yes	N.a.	N.a.	Yes	N.a.	N.a.
	13	Energy from incineration substitutes heat?	N.a.	Yes	Yes	N.a.	Yes	Yes
	14	Energy from incineration substitutes electricity?	N.a.	Yes	Yes	N.a.	Yes	Yes
	15	Alternative use of incineration capacity included?	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	No inf.	No inf.	No inf.	No inf.	No inf.	No inf.

* Details not directly available. Data in report is derived from 'Ökobilanzdaten für weissblech und ECCS' Infomationszentrum Weissblech, October 1995

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.
GWP	Recycling favourable in all cases			Recycling favourable in all cases		
Energy related impacts, other (Acidifica	Recycling favourable in all cases			Recycling favourable in all cases		
Saving (tonne CO2-eq/tonne steel)	1,29	1,30	0,22	1,29	1,30	0,22
Toxicity (pm10)	Recycling favourable in all cases			Recycling favourable in all cases		
Waste	Recycling favourable in all cases			Recycling favourable in all cases		
Other	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.	No Inf.

** Note that only toxicity related to particles is accounted for. The results for other toxicity categories could be different.

Values are rounded up (or down) to
nearest multiplum of 25%

Study:

01 Greenhouse gas emissions, life-cycle inventory and cost-efficiency of using laminated wood instead of steel construction. Case: beams at Gardermoen airport

Study commisioner:

Agricultural University of Norway,

Comments:

Scenario	Laminated wood construction for roof	Laminated wood construction for roof
Subscenario	Landfill	Landfill
Subscenario no.	1.1	1.2
Material type	Wood, laminated	Wood, laminated

System boundaries

Material production		*Virgin material*		
	1	Material marginal: Which?	Norwegian wood	Norwegian wood
	2	Electricity marginal: which?	66% Bio; 23% fossil; 11% norwegian electricity	66% Bio; 23% fossil; 11% norwegian electricity
	3	Steam marginal: Which?	N.a.	N.a.
	4	Co-products dealt with?	No	No
		Secondary material		
	5	Material marginal: Which?	N.a.	N.a.
	6	Electricity marginal: Which?	N.a.	N.a.
	7	Steam marginal: Which?	N.a.	N.a.
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	No	No
	10	Type of product dependent material recovery	N.a.	N.a.
Material disposal	11	Disposal comparison	Incineration	Incineration
	12	Emissions from landfill included?	Yes	Yes
	13	Energy from incineration substitutes heat?	Yes*	Yes*
	14	Energy from incineration substitutes electricity?	Yes*	Yes*
	15	Alternative use of incineration capacity incl.?	No Inf.	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	N.a.	N.a.

*both electricity and heat, ratio not specified

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	-136%	-120%
Resource consumption	No Inf.	No Inf.
Global warming	-135%	-98%
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	-2,31	-1,69
Other energy related impacts, SO_2 eq.	No Inf.	No Inf.
Toxicity; water	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Study:

02 Greenhouse gas balance implications of recovered wood in Sweden and Finland

Study commisioner:

Comments:

Scenario	Recovered wood from demolition	Recovered wood from demolition
Subscenario	Landfill	Landfill
Subscenario no.	2.1	2.2
Material type	Wood	Wood

System boundaries

Material production	*Virgin material*			
	1	Material marginal: Which?	Swedish wood	Finnish wood
	2	Electricity marginal: which?	Fossil	Fossil
	3	Steam marginal: Which?	N.a.	N.a.
	4	Co-products dealt with?	No	No
	Secondary material			
	5	Material marginal: Which?	N.a.	N.a.
	6	Electricity marginal: Which?	N.a.	N.a.
	7	Steam marginal: Which?	N.a.	N.a.
	8	Co-products dealt with?	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	No	No
	10	Type of product dependent material recovery	N.a.	N.a.
Material disposal	11	Disposal comparison	Incineration	Incineration
	12	Emissions from landfill included?	Yes	Yes
	13	Energy from incineration substitutes heat?	Yes*	Yes*
	14	Energy from incineration substitutes electricity?	Yes*	Yes*
	15	Alternative use of incineration capacity incl.?	No Inf.	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	N.a.	N.a.

*both electricity and heat, ratio not specified

Impact Assessment - e.g. recycling compared to incineration: (recycling - incineration)/incineration x 100%

Energy	No Inf.	No Inf.
Resource consumption	No Inf.	No Inf.
Global warming	-170%	-216%
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	-0,66	-0,66
Other energy related impacts, SO_2 eq.	No Inf.	No Inf.
Toxicity; water	No Inf.	No Inf.
Waste	No Inf.	No Inf.
Other	No Inf.	No Inf.

Study:

03 Environmental and energy balances of wood products and substitutes

Study commisioner: FAO

Comments:

Scenario	Recovered wood from demolition of blockhouse	Recovered wood from demolition of 3 storey house	Recovered wood from demolition shed (roof construction)
Subscenario	Landfill	Landfill	Landfill
Subscenario no.	3.1	3.2	3.3
Material type	Wood	Wood	Wood

System boundaries

Material production	*Virgin material*				
	1	Material marginal: Which?	No Inf.	No Inf.	No Inf.
	2	Electricity marginal: which?	Fossil	Fossil	Fossil
	3	Steam marginal: Which?	N.a.	N.a.	N.a.
	4	Co-products dealt with?	No	No	No
	Secondary material				
	5	Material marginal: Which?	N.a.	N.a.	N.a.
	6	Electricity marginal: Which?	N.a.	N.a.	N.a.
	7	Steam marginal: Which?	N.a.	N.a.	N.a.
	8	Co-products dealt with?	N.a.	N.a.	N.a.
Material recovery	9	Product dependent material recovery included?	No	No	No
	10	Type of product dependent material recovery	N.a.	N.a.	N.a.
Material disposal	11	Disposal comparison	Incineration	Incineration	Incineration
	12	Emissions from landfill included?	No, CH4 emissions from landfil is not included	No, CH4 emissions from landfil is not included	No, CH4 emissions from landfil is not included
	13	Energy from incineration substitutes heat?	Yes*	Yes*	Yes*
	14	Energy from incineration substitutes electricity?	Yes*	Yes*	Yes*
	15	Alternative use of incineration capacity incl.?	No Inf.	No Inf.	No Inf.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	N.a.	N.a.	N.a.

*both electricity and heat, ratio not specified

Impact Assessment - e.g. recycling compared to incineration: (recycling -

Energy	No Inf.	No Inf.	-64%
Resource consumption	No Inf.	No Inf.	No Inf.
Global warming	The study concludes that incineration causes less impact than landfill.	The study concludes that incineration causes less impact than landfill.	The study concludes that incineration causes less impact than landfill.
Saving, [tonne CO_2 eq. / tonne wood]. A negative value indicates a saving	-1,01	-2,56	-1,15
Other energy related impacts, SO_2 eq.	The study concludes that incineration causes less impact than landfill.	The study concludes that incineration causes less impact than landfill.	The study concludes that incineration causes less impact than landfill.
Toxicity; water	No Inf.	No Inf.	No Inf.
Waste	No Inf.	No Inf.	No Inf.
Other, POCP and eutrophication	The study concludes that incineration causes less impact than landfill.	The study concludes that incineration causes less impact than landfill.	The study concludes that incineration causes less impact than landfill.

Study:

AG-1 Sara, B.; Antonini, E.; Tarantini, M., (2000): Application of Life Cycle Assessment (LCA) methodology for valorization of building demolition materials and products

Proceedings of SPIE - The International Society for Optical Engineering, 9 p.

Study commisioner:

EU - LIFE programme

Comments:

"Traditional disposal": majorily landfill, "Valorization of waste": majorily recovery, reuse and recycling

Scenario	Disposal of construction & demolition waste	Disposal of construction & demolition waste
Subscenario	Landfill/ recycling (incl. avoided processes)	Landfill/ recycling (excl. avoided processes)
Subscenario no.	AG-1.1	AG-1.2
Material type	Aggregates	Aggregates

System boundaries

Material production	*Virgin material*			
	1	Material marginal	No Inf.	No Inf.
	2	Electricity marginal: which?	No Inf. (probably Italian average)	No Inf. (probably Italian average)
	3	Steam marginal: which?	No Inf.	No Inf.
	4	Co-products dealt with?	No Inf.	No Inf.
	Recovered material			
	5	Material marginal	site-specific	site-specific
	6	Electricity marginal: which?	No Inf. (probably Italian average)	No Inf. (probably Italian average)
	7	Steam marginal: which?	No Inf.	No Inf.
	8	Co-products dealt with?	No	No
Material recovery	9	Product-dependent material recovery included?	Yes	Yes
	10	Type of product-dependent material recovery	Various processes	Various processes
Material disposal	11	Disposal comparison	Landfill	Landfill
	12	Emissions from landfill included?	No inf. (probably yes)	No inf. (probably yes)
	13	Energy from incineration substitutes heat?	N.a.	N.a.
	14	Energy from incineration substitutes electricity?	N.a.	N.a.
	15	Alternative use of incineration capacity included?	N.a.	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:1	1:1

Impact Assessment - e.g. recycling compared to landfill: (recycling - landfill)/landfill x 100%

Energy	-5656%	-7%
Resource consumption	-541%	-100%
Global warming	-1240%	-10%
Saving, [tonne CO_2-eq. /tonne C&D waste]	-57,17	-0,70
Other energy related impacts, Acidification	-791%	-13%
Toxicity; human, air	No Inf.	No Inf.
Waste	-102%	-100%
Other, road transport	46%	46%

Study:

AG-2 Craighill and Powell (1999): A Lifecycle Assessment and Evaluation of Construction and Demolition Waste

Study commisioner:

CSERGE, UK

Comments:

Functional Unit: 1 tonne waste material, "Recycling" takes place off site, "Reuse" on site

Scenario	Landfill of construction & demolition waste	Landfill of construction & demolition waste	Landfill of construction & demolition waste	Landfill of construction & demolition waste
Subscenario	Landfill/ recycling 50:50	Landfill/recycling/reuse 33:33:33	Reuse/recycling 50:50	Reuse
Subscenario no.	AG-2.1	AG-2.2	AG-2.3	AG-2.4
Material type	Aggregates	Aggregates	Aggregates	Aggregates

System boundaries

Material production	*Virgin material*					
	1	Material marginal	No Inf.	No Inf.	No Inf.	No Inf.
	2	Electricity marginal: which?	UK average	UK average	UK average	UK average
	3	Steam marginal: which?	No Inf.	No Inf.	No Inf.	No Inf.
	4	Co-products dealt with?	No Inf.	No Inf.	No Inf.	No Inf.
	Recovered material					
	5	Material marginal	site-specific	site-specific	site-specific	site-specific
	6	Electricity marginal: which?	UK average	UK average	UK average	UK average
	7	Steam marginal: which?	No Inf.	No Inf.	No Inf.	No Inf.
	8	Co-products dealt with?	No	No	No	No
Material recovery	9	Product-dependent material recovery included?	Yes, and determined as zero	Yes, and determined as zero	Yes, and determined as zero	Yes, and determined as zero
	10	Type of product-dependent material recovery	Various processes	Various processes	Various processes	Various processes
Material disposal	11	Disposal comparison	landfill	landfill	landfill	landfill
	12	Emissions from landfill included?	Yes, and assumed zero due to inert material	Yes, and assumed zero due to inert material	Yes, and assumed zero due to inert material	Yes, and assumed zero due to inert material
	13	Energy from incineration substitutes heat?	N.a.	N.a.	N.a.	N.a.
	14	Energy from incineration substitutes electricity?	N.a.	N.a.	N.a.	N.a.
	15	Alternative use of incineration capacity included?	N.a.	N.a.	N.a.	N.a.
	16	In which ratio does recycled material substitute virgin material ? (1:1 or 1:0.5 or other)	1:0.9 ("additional primary material is required")	1:0.9 ("additional primary material is required")	1:0.9 ("additional primary material is required")	1:0.9 ("additional primary material is required")

Impact Assessment - e.g. recycling compared to landfill: (recycling - landfill)/landfill x 100%

Energy	-8%	-30%	-46%	-76%
Resource consumption	-47%	-63%	-94%	-95%
Global warming	-10%	-32%	-48%	-77%
Saving, [tonne CO_2-eq. /tonne C&D waste]	-0.001	-0.004	-0.006	-0.010
Other energy related impacts, Acidification	-13%	-31%	-50%	-75%
Toxicity; human, air	-11%	-33%	-50%	-78%
Waste to landfill	-47%	-63%	-94%	-94%
Other, road transport	9%	-25%	-38%	-94%