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Miljøprojekt

Waste Indicators

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Preface

The project on “Development of indicators to follow effects of initiatives within waste and recycling” was approved by the Danish Environmental Council for Cleaner Products in the summer of 1999. However, with the acceptance of the Danish Environmental Protection Agency project start-up was postponed for six months.

During the project, four steering committee meetings have been held with the participation of Berit Hallam, Jette Skaarup (first meeting) and Lone Lykke Nielsen (from second meeting), all from the Danish Environmental Protection Agency, and Carsten Lassen and Ole Dall from COWI.

In the first phase of the project, an analysis was carried out of existing methods and data basis for assessing possibilities of setting up life-cycle-based indicators for waste treatment. In the second phase of the project the proposed indicators have been tested on three material fractions: paper, glass packaging and aluminium.

The project is a pilot project, and the intention has not been to present a final and complete result of an indicator calculation for the entire waste management field. Thus, the project report only presents examples from selected fractions that are summarised in Chapter 1. Emphasis has been on discussing calculation methods, data basis and application of results. Methodological considerations and assumptions for calculations are presented in the report and its appendices.

The project report gives a description of the purpose and extent of carrying out a calculation of indicators for the entire waste management field. Furthermore, the report contains a Glossary explaining life-cycle and waste terms used.

The project has been carried out by a working group consisting of Ole Dall, Carsten Lassen and Erik Hansen, all from COWI, Rådgivende Ingeniører AS.

The project was completed in January 2002.

Summary and conclusions

The aim of this pilot project was to investigate the extent to which life-cycle-based indicators could be calculated and applied to help prioritise efforts in the field of waste management, and follow the development of waste management in an environmental and resource perspective.

A preliminary analysis of the environmental effects of managing individual waste fractions showed that a number of environmental impacts should be included in the assessment. However, completing relevant life-cycle-based calculations that take all environmental impacts into account is not possible, because the data required is not available. It is particularly difficult to obtain accurate data on the content of toxic and persistent substances in waste.

Three life-cycle-based indicators are proposed for all waste fractions that reflect *resource consumption*, *primary energy consumption*, and *landfill requirement*. These indicators supplement each other, but do not necessarily provide a complete picture of the environmental effects of waste management. Resource consumption reflects the overall unit for materials that are consumed during waste management. Primary energy consumption is chosen as an indicator for various environmental impacts such as global warming and acidification, which are primarily linked to energy consumption. The landfill requirement indicator specifies the total landfill space needed for disposing of waste from the entire life-cycle of a given waste fraction.

An important point of discussion throughout the project has been which indicators it is possible to calculate compared to the environmental impacts that these indicators reflect. These discussions have led to the results being presented in two different ways each with their distinct strengths and weaknesses. For both models, incomplete and uncertain data means that the indicators should be regarded as a helpful tool in the decision making process, which involves a variety of factors. The continuous publication of indicator values to a wider audience will require careful presentation of the main assumptions and uncertainties.

Model A provides a kind of overview of the resource consumption and environmental effects of the majority of waste fractions. However, this would be a rather comprehensive and time-consuming task. In addition, the results would primarily be useful in a discussion of the extent to which there is a need to reduce waste generated during the production and consumption phases of a product's life-cycle, which is beyond the scope of this project.

Model B, on the other hand, adequately fulfils the most important aim of calculating life-cycle-based indicators, namely to identify the most significant potential resource and environmental savings associated with further optimising waste management operations. At the same time, Model B would be able to document that efforts to minimise the environmental impacts of waste management have so far proven to be effective.

Model B can be carried out initially with eight man-months and can be updated annually with an effort of around two man-months (incl. provision and updating of LCA data).

1 Waste indicators - trial run

Part of the project involved a trial run of the indicators, which were calculated for three selected material fractions, namely paper and cardboard, glass packaging and aluminium. The purpose of this trial run was not to present a final, complete result of the indicators. The calculations should therefore be considered as examples that illustrate how the indicators can be used and presented. The indicators calculated for the three fractions will inevitably have to be updated, in the event that indicators are calculated for the entire field of waste management. In this chapter results of calculations are summarised. In Chapter 5 and Appendix D all results as well as the calculation basis are presented. Appendix D has not been translated.

The indicators are based on life-cycle considerations, which implies that resource consumption and environmental effects are included from the extraction of raw materials to waste disposal. As principle all input and output flows are included in the calculation. But when practising the impact assessment it will be necessary to leave out some input and output due to lack of data. It will therefore be urgent to mention this by presentation of the results.

In the calculations, it is assumed that new materials are to be produced to substitute all waste materials that are discarded. If material is disposed of by landfilling, resources and energy will be required for the production of new material. Waste will also be generated during the extraction and processing of new material. If material is recycled instead of being landfilled, less new material will have to be produced. Similarly, some energy can be recovered from waste material with a calorific value.

The calculation of indicators is based on a series of assumptions and are also subject to a certain degree of uncertainty. The results are therefore not suited for presentation to a wide audience, but can form part of the basis for making decisions, with the aim of prioritising efforts to optimise waste management. This includes both an assessment of which waste fractions have the greatest resource consumption and environmental impacts and which treatment options are the most appropriate for each waste fraction. Indicators can thus supplement the existing information on individual waste quantities for waste fractions, sources and treatment options, thereby making it possible to prioritise efforts to minimise the resources consumed and environmental impacts of waste management, as well as efforts to avoid treatment options that increase the total landfill requirements throughout the life-cycle of a given material.

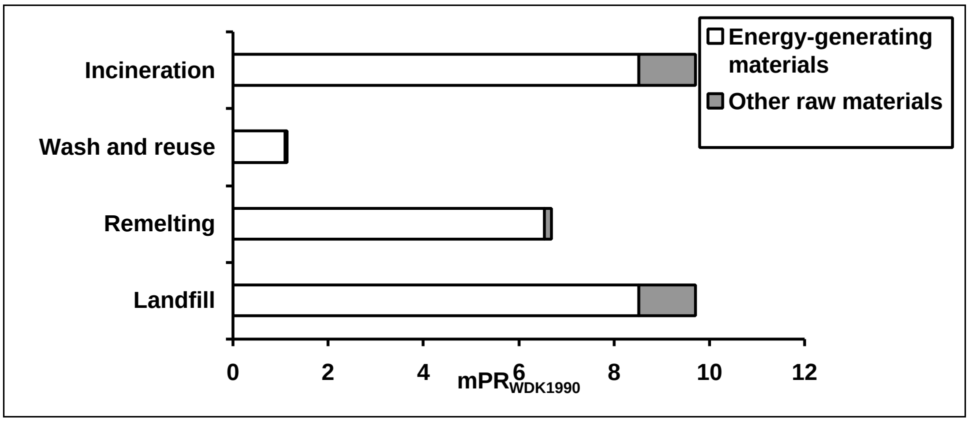
1.1 Preliminary calculations of waste indicators

The aim of testing the indicators for a few selected material fractions was to investigate how easy it is to obtain the necessary data and assess the time required to complete the calculations. It has also been possible to try out different ways of presenting the results, and two different presentation methods are suggested.

Both presentation methods (referred to as Models A and B) are based on similar calculation parameters describing the life-cycles of the materials, but differ in terms of the need for precise quantitative data for individual material fractions. Data requirements are crucial for assessing the scope of work involved in calculating indicators for entire waste management systems.

LCA-based parameters for resource consumption, energy consumption and landfill requirement must be determined for each treatment option for the individual waste fractions. The methods and principles are described in the project. Figure 1.1 is an example of the parameters calculated for glass packaging showing resource consumption for the relevant waste treatment options. Similar profiles for resource consumption, energy consumption and landfill requirements are presented in the project for paper, glass and aluminium.

Figure 1.1 Net total resource consumption associated with the treatment of 1 tonne of glass and the production of substitute material required for different waste treatment options



The units are milli person-reserves mPR. $PR_{WDK1990}$ is the unit for resource consumption, expressed by weighting relative to the person-reserves estimated for World/Denmark (WDK) in 1990. (See Glossary)

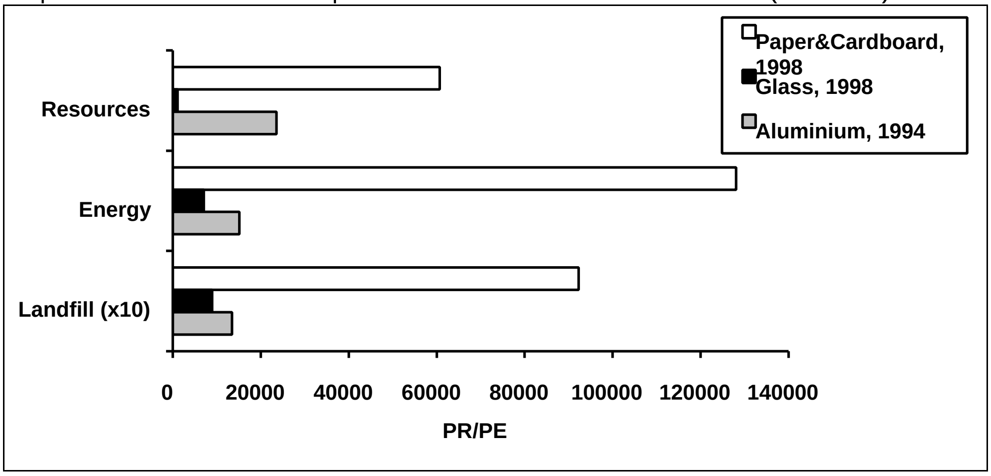
In the first presentation model (A), the parameters mentioned above for each waste fraction and treatment option are multiplied by the total quantity of each waste fraction treated by each treatment option. For example, the quantity of glass packaging, in tonnes, that is incinerated at a waste-to-energy plant is multiplied by 9.7 mPR per tonne (see Figure 1.1). The results for each of the four treatment options are summed up and represent the indicator value for resource loss for managing waste glass. The results for the three indicators and materials are shown in Figure 1.2.

Model A represents the amount of virgin resources that are required for a given material to regain its original value after the material has been used and managed as waste. In Model A, all losses of utility value that occur during the life-cycle of a product are attributed to waste management, i.e. allocation of resources and environmental impacts to the different phases in a product’s life-cycle does not occur (see Glossary). This is acceptable since the aim is to compare different waste treatment options and not to give an absolute representation of the environmental impacts of waste management.

Model B calculates the resource and environmental advantages that are associated with recycling waste and recovering materials or energy as opposed to simple landfilling of the waste. The basis for the calculation is the same as in Model A, where the indicator value for a given treatment option is multiplied by the waste quantity treated. In Model B the calculations are based on the differences in indicator values and waste volumes for the different waste treatment scenarios.

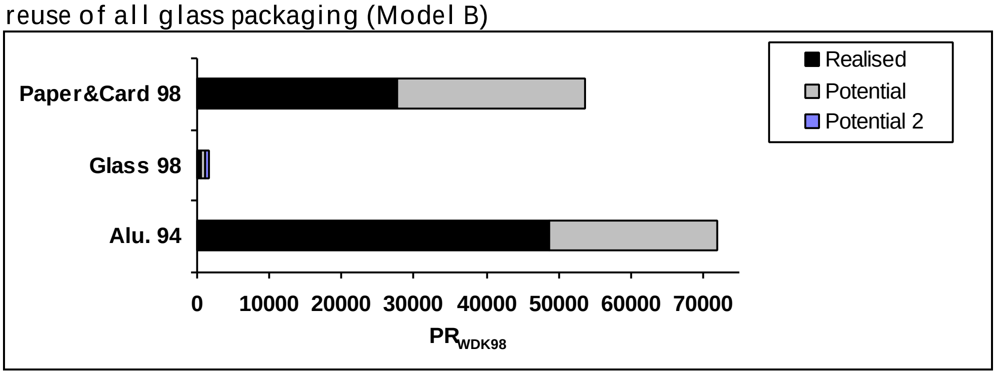
Thus, Model B compares the different treatment options and does not present an absolute value for the resource consumption and environmental impact of different waste fractions. Model B illustrates the resource and environmental savings realised by the present management of the waste fractions compared to landfilling all the waste generated. If desired, Model B can be developed to include a partly estimated calculation of the potential savings that could be achieved by managing waste in an optimal way, which is also attempted in the project. Figure 1.3 is an example of these savings potentials.

Figure 1.2 Use of resources, energy and landfill space associated with the disposal of waste and the production of substitute material (Model A)



The following units have been used: Resource consumption: $PR_{WDK1990}$; Energy consumption:
$PE_{Energy\ DK98}$; Landfill requirement: $PE_{Waste\ DK98}$. For more detail, see Glossary. The values for landfill requirement should be multiplied by 10. It should be noted that the three indicators have only been shown in the same figure for practical reasons. Each indicator should be studied separately.

Figure 1.3 Realised savings by the current treatment and potentials for further savings in the total resource consumption associated with the disposal of three material fractions. "Potential 2" represents washing and reuse of all glass packaging (Model B)



The units are person-reserves mPR (see Glossary).

The significance of the potential savings can be questioned, as well as the choice of treatment options that are used to calculate the savings. In the example, the potential savings for glass packaging are calculated assuming that all glass packaging is recycled or reused. It appears that in relation to resource consumption, it is much more important to recycle aluminium and paper and cardboard, than to recycle glass. It is also seen that significant additional resources could be saved for the waste fractions paper and cardboard and aluminium. However, it is important to compare the resource indicator with the two other indicators for energy consumption and landfill requirement (see Chapter 5), and possibly include other assessments, such as potential release of toxic substances to the surroundings, before any final conclusions are drawn.

1.2 Calculating indicators for the entire waste management system

If the aim is to obtain an overview of the relative contribution of different waste fractions to resource consumption and environmental impacts on the surroundings, Model A is the most appropriate. In this way, it is possible to identify the areas where the environmental impacts of waste management could be reduced *by reducing waste generation* or by encouraging the use of alternative materials during manufacturing. The approach is interesting but mainly suggests that changes should be made in the manufacturing process and in consumer behaviour, which is beyond the scope of this project.

If, on the other hand, the aim is to focus on the resource and environmental savings resulting from *optimising waste management*, Model B is sufficient. Calculating Model B for all waste fractions would allow the most significant potential resource and environmental savings during waste management to be identified. It would also be possible to supplement with calculations that focus on identifying the fractions with the greatest savings potentials. Finally, it would be possible to limit the assessment to certain specific fractions in order to determine the resource and environmental savings associated with the different waste treatment options.

Both presentation methods are based on similar calculation parameters describing the life-cycles of the materials, but differ in their need for precise quantitative data for individual material fractions. Model B is the least demanding, since it primarily uses data that can be obtained from waste management statistics describing the waste quantities and treatment options for individual waste fractions. Although it is not necessary to accurately determine the total flow of material in society in order to calculate the indicator values, as it is for Model A, additional data must be obtained in order to calculate the potential for optimising waste management. However, this data collection exercise can to a certain extent be replaced by qualified estimates, without adversely affecting the overall calculation results.

No matter which model is selected – A or B – life-cycle-based factors must be calculated for around 50 material fractions disposed of in two to four different ways. Such data is widely available in the EDIP PC tool database or other LCA databases, but must be supplemented or updated in a number of fields. It is estimated that around two man-months will be needed for initial calculation of the life-cycle-based factors, and around ½ man-month for an annual updating.

For quantitative data, the extent depends on the model selected. It is assessed that for a calculation of the entire waste management field for Model A 10 – 20 man-months are required to provide quantitative data for all material fractions, possibly 10 man-months more if suitable mass-flow analyses or material flow statistics for a number of relevant materials cannot be found.

If Model B is selected with a calculation of realised savings and selected savings potentials from optimisation of waste management, the amount of time required to provide quantitative data will be around three to five man-months. Model B can be updated annually with an input of around one to 1½ man-months.

2 From waste quantities to environmental impacts

In this chapter, the general idea of developing indicators in the field of waste management is described. Furthermore, the difference between indicators for environmental impacts and existing quantitative waste statistics is discussed.

2.1 Present indicators for waste management

Indicators applied today to follow developments in waste and recycling in Denmark are merely quantitative statements of total waste quantities broken down on treatment and disposal options.

For each waste category the following indicators are used:

- Total waste quantities – in some cases stated per capita
- Disposal pattern distributed on special treatment, recycling, incineration and landfilling – in some cases stated in per cent.

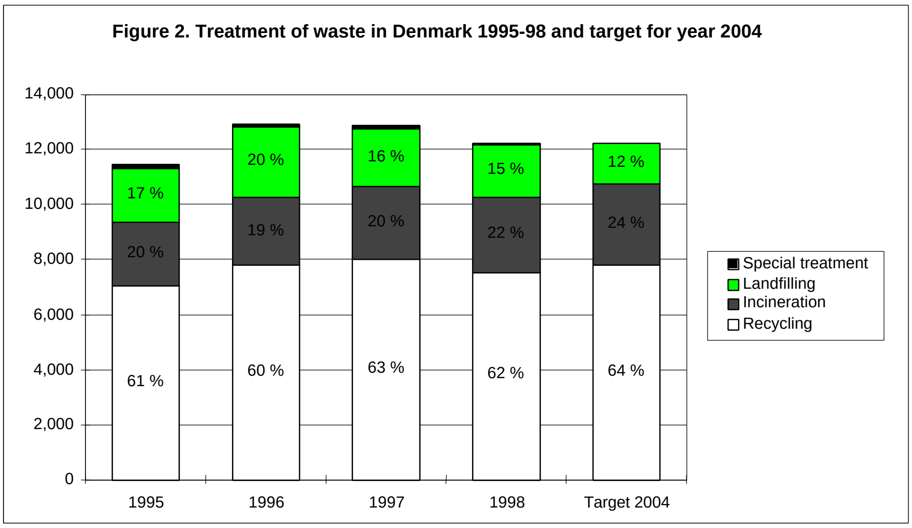
The basis for development of these indicators is the present waste management strategy – called the waste hierarchy – ranging the different treatment and disposal options as follows: Waste prevention > recycling > incineration > landfilling. Indicators are simple, indisputable and may be used unambiguously to illustrate compliance with political objectives. However, objectives are formulated more with respect to reducing waste generation rather than with the direct aim of reducing energy, resource and environmental impacts from waste management.

It should be noted that whereas disposal patterns depend on political measures within the waste management field, waste prevention rather depends on measures in relation to manufacture and consumption of products. However, consumption is beyond the scope of this project, which focuses on disposal by incineration or landfilling or on reuse/recycling of waste.

2.1.1 Existing statistics on waste

Figure 2.1 is reproduced from Waste Statistics 1998. It compares total waste quantities and treatment with objectives for year 2004 in the Danish Government's Waste Management Plan.

Figure 2.1 *From "Waste Statistics 1998" /40/*



Target 2004: Target for year 2004 in the Danish Government's Waste Management Plan /37/.

General waste indicators are determined today by aggregating all waste categories on the basis of quantities. In aggregated indicators (as in Figure 2.1) garden waste quantities, for example, have the same weight as scrap aluminium quantities, even if environmental impacts are very different.

It is important to realise that new LCA-based indicators for waste are expected to serve as a tool in particular for public authorities responsible for waste management. Present statistics serve the same purpose, since planning of new initiatives for waste and recycling is based on, for example, existing knowledge of the extent of waste problems and present management. Planning of treatment capacity and financial optimisation of, for example, incineration, landfilling or reprocessing plants for recycling often requires detailed knowledge of waste streams. Also national initiatives to regulate waste quantities and treatment options require a statistical basis for mapping and analysing development needs.

The Danish Information System for Waste and Recycling – the ISAG – is based on a statement of collected waste quantities in a number of categories in harmony with EU legislation and the so-called EWC codes for hazardous waste. Waste treatment plants are responsible for registration and reporting to the authorities. As ISAG registrations are well-established and the use of EWC codes is relatively new in Denmark, ISAG statistics are in many ways more accurate, even if – in principle – EWC codes give a more detailed picture for hazardous waste.

It is estimated in the project whether ISAG statistics can be used as the basis for an indicator calculation. Once the use of EWC codes has gained more ground it may be relevant to include this registration in a future indicator calculation to the extent that hazardous waste is to be included.

The ISAG system contains data for fractions subjected to separate waste treatment, such as paper for recycling or domestic waste for incineration. For a number of fractions, waste statistics may be related to and supplemented with other statistics. For example, production and supply statistics may be related to waste statistics, thus giving a picture of the destiny of goods manufactured in the fractions of waste statistics. So far this has been done for a number of materials in the so-called material flow statistics. In this way it is possible to calculate for a number of material fractions the proportion of materials consumed that is disposed of by recycling, incineration or landfill.

There are two central ways of presentation and use of waste statistics:

1. Developments in total waste quantities broken down on sources and sectors such as households, industry and commerce, bulky waste etc. Such statements make it possible to target efforts in the waste management field towards the most relevant sectors.

2. Treatment options broken down on a number of waste types. Treatment options cover recycling, incineration, landfilling and special treatment. For waste led to recycling, statistics are broken down on a number of specific material fractions. The statement makes it possible to calculate the rate of recycling, expressing to some degree compliance with political objectives for increased recycling.

Present statistics form the basis for planning of waste management, for example in relation to extension of treatment capacity. When, in fact, it is problematic to only look at quantities and rates of recycling for the different sources of waste, it is because environment and resource problems relating to the different waste fractions are not stated and assessed. Neither is it possible to assess environment and resource issues relating to different treatment options for waste fractions, and the advantages of one treatment option over another do not appear.

In addition, a number of environmental issues exist beyond waste management as such, but for which waste treatment has decisive influence on environmental impacts. New indicators therefore must be based on a life-cycle perspective, incorporating in principle all environment and resource related changes caused by the different waste treatment options.

2.1.2 Purpose of new indicators

Below, the possibilities of developing indicators to reflect also more directly the resource and environmental impacts caused by waste management are discussed. Indicators will be developed from a life-cycle perspective. In the considerations it is essential to have two levels of indicator use in mind:

Total waste quantities. In a comparison and aggregation of indicators for the different waste fractions, new indicators may to a higher extent reflect real energy, resource and environment-related consequences of developments in the field of waste management. This type of statement may be used to prioritise efforts based on waste fractions constituting the largest impact or the largest loss of resources. However, to do this it must be possible to develop indicators that can be applied to most waste fractions.

Individual waste fractions. New indicators on individual waste fractions may take into consideration that the waste hierarchy for different treatment and disposal options in some cases does not reflect real differences from an environmental perspective. Such use of indicators does not require that indicators are applicable for several waste fractions, but rather that they contain data allowing for comparison of different treatment options for the same waste fraction. What is important here is to show resource and environment-related differences among treatment options.

Finally, it is important to bear in mind that ambitions for use of indicators may differ. If the purpose is to follow closely developments over a number of years, and indicators should be used to adjust waste policies continuously, it is important that indicators can be updated regularly – for example annually, and that analyses are available within a reasonable time frame.

However, if it is the ambition to draw up a status at, for example, five-year intervals, and it is acceptable that completion of the analysis is relatively time-consuming, requirements for data sources are different. In this case it will be possible to a higher extent to draw on statuses, specific studies of individual fractions etc.

The purpose of establishing indicators is to supplement quantitative statements with environment-related indicator values liable to be incorporated in the basis for prioritisation in the revision of waste planning. It is expected that this will be done continuously, but with an overall revision every three to five years.

The aim of the present project is to establish indicators that may be updated annually for all waste fractions so that environment and resource indicators are available that may supplement existing waste statistics. Due to insufficient data, however, it may be necessary to change the objective for completion of indicator calculations. For some waste fractions it is expected that calculations will be completed only with some years' interval. Chapter 6 discusses which fractions are relevant for continuous update and which are relevant for periodic updates.

2.2 Indicators developed for LCA

In the development of new indicators for waste management based on life-cycle considerations, it will be expedient first to relate to indicators used within LCA, and in particular the Danish EDIP method /11/(Environmental Design of Industrial Products) (see Glossary).

Generally, the EDIP method deals with five groups of indicators, related to the following areas:

- Environmental impacts
- Health aspects not related to working environment
- Working environment impacts
- Resource consumption
- Solid waste

For 'environmental impacts' and 'resource consumption' methods have been developed, allowing to some degree to aggregate impacts by weighting the individual indicators. Below, indicators and opportunities in the environment and resource area are briefly outlined.

2.2.1 Environment and resource indicators in EDIP

The following indicators are included in the EDIP method at present:

- Global warming
- Acidification
- Eutrophication
- Stratospheric ozone depletion
- Photochemical ozone formation
- Acute ecotoxicity
- Acute human toxicity
- Persistent human and ecotoxicity
- Working environment
- Resource consumption
- Bulky waste
- Hazardous waste
- Radioactive waste
- Slag and ash

So far, sufficient analyses of environmental impacts from waste disposal in a long-term perspective have not been conducted. Therefore, the EDIP project uses the four above waste categories led to landfill as a kind of aggregated indicator for environmental impacts from waste disposal.

Waste quantities are stated in unit of weight and normalised in relation to total Danish waste quantities in each waste category. To calculate emissions and thus environmental impacts from selected waste treatment and landfilling processes in Denmark, the Danish Environmental Protection Agency has launched a project on "LCA and landfilling of waste" /22/. Preliminary results of this work are that the working group recommends replacement of waste categories with contribution to other impact categories, and two new impact categories:

- Toxic impacts in the first 100 years, included under the other impact categories on toxicity,
- "Landfilled toxicity", which is a new impact category stating toxicity potential of landfilled waste in a long-term perspective,
- “Landfill requirement”, to be replaced by land occupation once this category has become operational. However, methods have not yet been developed to work with land occupation under the EDIP method. However, exactly for waste disposal it would be relevant to have this aspect included.

2.2.2 Aggregation of environment and resource parameters in EDIP

The EDIP method only aggregates data in the grouping of the different impact categories as mentioned above (see Glossary). But to bring the size of impact categories to the same scale, for each impact category, furthermore, a normalisation is carried out in relation to global or regional emissions or consumption per person (see Glossary). This means that all emissions or consumption are expressed as person-equivalents (PE) in relation to present consumption and emission per person. Person-equivalents express how large a proportion of present consumption or emission may be attributed to the product or area under review.

The EDIP method, in addition to normalisation, suggests how to weigh some impact categories so as to make them more comparable – however without making a direct aggregation of the individual factors (see Glossary). However, in principle it will be possible to do so for environmental impacts and resource consumption respectively, which has also been done in several other contexts.

Environment and health parameters: If a weighting is made of the many types of environmental impacts, it is advantageous to distinguish between human and ecotoxicological parameters and other parameters, the former being in general very uncertain and often lacking good data for statements.

Resource consumption in the EDIP method is handled by relating consumption of each resource to total global reserves of the resource in question. A distinction is made between renewable and non-renewable resources. Renewable resources are weighted with 0, unless they are extracted to an extent that the accessible quantity is presently being reduced- - for example, the resource “groundwater” in Denmark the extraction of which in certain parts of the country is larger than its regeneration. Weighted resource consumption thus achieved may be aggregated to a collective indicator for resource consumption.

Waste disposal by landfilling in the EDIP method is handled with the above four different waste categories led to landfill, as so far no statements have been made of release to the surroundings of pollution and resources for the entire period of landfilling. Waste to landfill is derived from all life-cycle phases; for example, mining waste is also included in the four waste categories. However, accessible databases are often insufficient in this respect. Waste landfilling may be aggregated according to the same principle as other environmental EDIP parameters, i.e. it can be normalised and weighted with the political reduction objectives.

Working environment, from experience, is difficult to handle, if the assessment comprises many different processes. In the ongoing project on further development of the EDIP, a preliminary report has been published, quantifying working environment impacts in a number of sectors, based on existing statistics.

However, waste treatment and recycling industries have not been stated separately, partly because the sector is relatively new and small and therefore not treated separately in overall statistics, and partly because systematically collected experience with working environment in the recycling industries is very limited /19/. However, a number of studies of working environment conditions in waste management have been launched, and thus it will probably be possible to acquire relevant data at a later stage.

2.3 New indicators in the field of waste management

In Chapter 4 methods for calculation of new waste indicators are reviewed on the basis of resource and environment issues associated with disposal of the different waste fractions. Results will be presented in two basically different ways, based on the same calculation principles.

2.3.1 Basic principle for indicator calculation

The calculation of life-cycle-based indicators for waste management is based on the principle that society’s material consumption is constant or increasing in the period of time for which the calculation should be used. This means that if any material is removed from circulation, either through landfilling or incineration, virgin raw materials must enter the system to replace what was lost. However, it is possible that in a mapping of the entire field of waste management, materials will appear for which this assumption does not hold true. This may be the case, for example, for use of materials that are undesirable from an environmental viewpoint, and a decision has been taken to phase them out completely. In such a situation the consequence may be that recycling of the material is of no value.

Another necessary assumption is to calculate parts of the life-cycle for products: parts concerning raw material and material production and waste treatment. To the extent that materials are recovered or replace other materials before they are lost through incineration or landfilling, they will also be incorporated in the calculation as a reduction of material consumption.

By contrast, product manufacture and use of products are not included in the calculation. This assumption was necessary, as it is not possible to get data on manufacture of products that ended up in a given waste fraction.

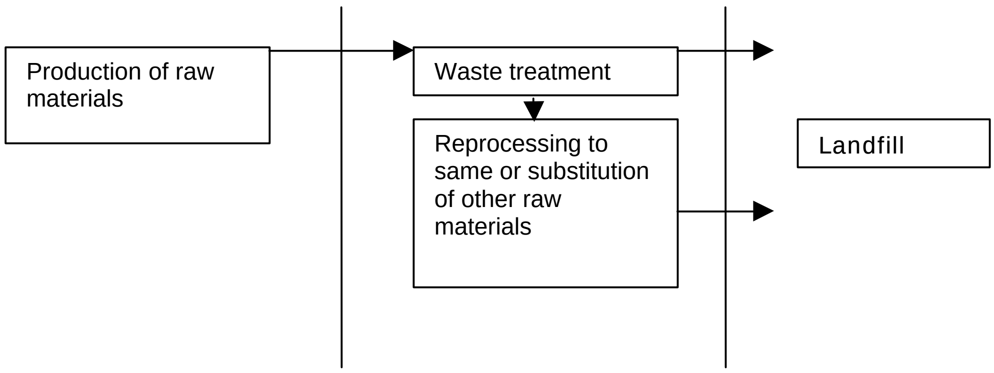


Figure 2.2 Illustrates the system boundaries in the calculation. Please note that product manufacture and use are not included

Of course, this model may be discussed, and it does influence the use of indicators. If the purpose is to assess which ”value” waste represents, the model should be extended to cover also some more detailed considerations on discarded products’ utility value and durability. Which utility features are we discarding and what was the cost of producing these products? Such questions easily trigger extensive and difficult considerations on how to distribute responsibility for a product’s material and utility features among designers and users of the product and those who are responsible for the product’s management as waste.

The calculation is based on the manufacture of materials lost in waste management in different ways. This result gives a calculated value for lost resources that may easily be confounded with an ”absolute value” for waste. For example, one tonne of aluminium led to landfill will have a higher value – be more expensive to dispose of – than one tonne of aluminium led to recycling.

As mentioned above, many factors of a material’s life-cycle are not included in the calculation, so in principle it would be more correct to use only calculations for looking at differences among different options for waste management. In this way some of the unknown factors are eliminated, and the result can still be used for expressing the efficiency of waste management. However, this does not exclude comparison of different materials. It only means that it is more correct to compare environment and resource *savings* from management of materials in different treatment systems.

2.3.2 Accessible data

One of the important features of the ISAG today is that the grouping of waste in sources or fractions is the result of a number of practical and historic issues. This division is not necessarily the most expedient for making, for example, an LCA assessment of waste management, and neither is it always the most expedient basis for giving an outline of the fate of different material fractions upon waste treatment. In general, emphasis has been put on statements of material flows treated separately, for example materials for recycling.

The purpose of continuous statistics as a supplement to the ISAG (see Chapter 3) is often to map waste streams for specific materials or products. Such statements are necessary for conducting an LCA assessment of waste streams. At the same time these statements form the basis for presenting LCA calculations at the material and product levels, which is also useful in connection with, for example, implementation of a product-oriented environmental policy.

In the longer-term perspective it may be relevant to try to adapt waste statistics, which is being done today on an ad hoc basis. The need for any new categories that may ease calculations of LCA-based indicators, will be treated in connection with the trial run under the present project on indicators for selected waste streams.

2.3.3 Presentation of results

Chapter 5 proposes two ways of presenting data, each focusing rather differently on the waste question. The two proposals are based on considerations of calculation principles and accessible data.

Whereas one of the proposals seeks to provide a total picture of environmental and resource impacts from waste using present management techniques, the other proposal puts focus on showing results achieved and, to some extent, which potentials may be gained from changing waste management. The two ways of presenting results of indicator calculations have slightly different assumptions for data, and they may supplement each other if data is available to conduct all calculations.

It should be noted that new indicators are to be seen as a supplement to indicators already in use in the waste sector. Waste quantities are still to be seen as an important indicator for the area and will still be used as the basis for design of, for example, landfills, incineration plants and other treatment plants. Furthermore, waste quantities within the different fractions still constitute an essential part of the basis for calculation of new indicator values. The new LCA-based values, by contrast, are expected to give a considerable contribution to the prioritisation of different waste fractions or treatment options.

2.3.4 Which indicators are relevant?

The analysis presented in Chapter 3 indicates that in addition to resource consumption and landfill requirement there are a number of different environmental impacts, for example eco and human toxicity, that are important in relation to differences among different treatment options for the different waste fractions.

On the basis of an analysis of accessible data for waste treatment presented in Chapter 3 and accessible data from the EDIP project, it is realistic to carry out calculations for *resource consumption, energy consumption and landfill requirement.*

Energy consumption is not used as a category in the EDIP, since energy consumption is included in resource consumption and derived environmental impacts. However, on the basis of EDIP data for energy resources it is relatively simple to calculate a primary energy consumption (see Glossary). Consequently, in the trial run, a parameter for primary energy will be calculated that may be normalised in relation to total Danish primary energy consumption. In this context, energy consumption should be seen as a measurement for a number of energy-related environmental impacts of which global warming is most directly linked to energy consumption. Resource consumption for energy is also included in the statement of resources, but here consumption is included as the weighted resources – and not due to their environmental impacts. In the resource statement it should also be possible to distinguish between energy and other resources, and it should be possible to distinguish between renewable and non-renewable resources.

For the *human and eco-toxicological parameters* used in the EDIP project, data is often insufficient. At the same time, the basis for calculations is insufficient for waste quantities, since waste statistics do not have the direct, detailed statements for different materials that are necessary for LCA calculations. This gives reason to re-evaluate the relevance of calculating ecotoxicological parameters as indicators in the field of waste management.

Previously, experience has been gained from including environmental impacts in large prioritisation projects. In connection with the project ”Environmental prioritisation of industrial products” /15/ originally only resource and energy consumption was included. A subsequent pilot project /10/ investigated whether it was possible to qualify prioritisation by including environmental impacts in the calculations. Experience showed that resources needed to collect data, particularly for toxicity parameters, were excessive compared to the outcome that was anyhow very uncertain. Similar experience has been gained in the project ”Environmental impacts in the family” /14/, in which inclusion of the environmental impacts of ecotoxicity and human toxicity was considered, but rejected.

Therefore it is suggested that these parameters are not included directly in the indicators to be tested. The omission of ecotoxicological parameters means, however, that indicators are not adequate for the assessment, for example, of hazardous waste, which as a consequence should be excluded from indicator calculations or supplemented with other assessments.

The analysis in Chapter 3 also indicates that for some waste fractions there may be significant differences in *working environment impacts* from different treatment options. However, it is extremely difficult to quantify working environment conditions in recycling industries. But principles for this may be set up, cf. sub-project on working environment in the ongoing development project on the EDIP method and data for LCA assessments. However, it is assessed that work required is excessive compared to the expected result, due to lack of data in this field.

Against this background it has been decided to use the parameters below. Determination of units is discussed in Chapter 4.2, and units used are explained in the Glossary.

Resource consumption (in PR – person reserves)
Resource consumption is stated by converting the weight of each individual material to a proportion of the existing resource basis. In other words: what is the proportion of a unit of weight of the material in relation to existing material quantities per person. For non-renewable resources, the existing quantity is calculated per person in the world, and for renewable resources in relation to accessible quantities per person in the region. If a renewable resource is regenerated at least as fast as present consumption, supply is infinite, and consumption is weighted at 0. For example, this applies to the use of surface water. Principles follow the statement methods of the EDIP project /11/.

Energy consumption (in PE – person equivalents)
The unit for energy consumption is annual primary energy consumption per person in Denmark, which is set equal to one person equivalent. This is not included in the EDIP project, but is used here as a total measurement for environmental impact from energy conversion.

Landfill requirement (in PE - person equivalents)
The unit for landfill requirement is the present landfill requirement for waste in Denmark per person. This parameter is used due to lack of more specific parameters for landfilling, which are being developed in connection with the LCA method. The indicator is different from the four waste categories for landfilling under the EDIP project, as all waste for landfilling is collected in one category.

3 Screening of environment and resource issues in waste management

The project started with a systematic review of the 22 main waste fractions in the ISAG system (see Appendix A). Hazardous waste was not divided into sub-fractions, as the indicators proposed are not expected to provide substantial new information on the environmental impacts of the fractions.

In the review of environmental issues for the 22 fractions, each fraction has been labelled with one or more crosses showing where there are significant differences in environmental impacts from typical treatment of the different fractions. Table 3.1 summarises these crosses, subsequently used in choosing parameters to be included in the new indicators. Data accessibility is another area of significant importance for the extent of work in the calculation of LCA-based indicators, and the result of the review is summarised in Table 1.1 in Appendix B. Accessibility and suitability of data are subsequently treated in more detail in Chapter 6 in connection with the assessment of the amount of time required to prepare indicators for the entire waste management field.

It is important to realise that the crosses in Table 3.1 are relative within the fraction, and that they express expected significant differences among the typical treatment options. Crosses are based on a life-cycle perspective, so that for example plastic incinerated instead of plastic recycled gives a cross for smog. Incineration leads to a need for production of virgin plastic giving a contribution to VOC pollution. Thus, crosses are meant to show where to find the “focal points” within the different waste fractions.

A comparison between information in the table and waste quantities registered for each fraction brings us closer to clarification of the waste fractions representing the largest environmental potentials for change, and those representing insignificant areas of effort.

3.1 Important parameters for all fractions

Table 3.1 summarises all tables of Appendix A where grounds are given for the allocation of the crosses in the table. It gives an outline of parameters with the largest impact in the choice of treatment option for all waste fractions.

Both energy-related resources and pollution, and resources not related to energy consumption are important in the choice of treatment option for by far the major part of waste fractions. In addition, landfill requirement is a possible consequence in the choice of treatment option for most waste fractions, and it is thus an important factor for a number of waste fractions.

Emission of toxic compounds to the environment is also a problem covering a large part of waste treatment. For toxic impacts, heavy metals or persistent organic compounds are found for almost all waste fractions. These substances cause problems – for some treatment options considerably more than for others. For all waste fractions with a cross in the energy column, the energy-related differences among the different treatment options may be considerable. Thus, there will be differences both in relation to influence on global warming and acidification that relate to energy issues. All energy-related environmental impacts are not included in the allocation of crosses in the other columns.

The only essential impact on global warming that is not related to energy consumption is the emission of methane gases from organic waste fractions, where the choice of treatment option may be of significance.

Regional impacts from acidifying or eutrophying pollutants that are not related to energy may be due to, for example, paper causing water contamination upon recycling.

Issues relating to working environment seem to be related to certain manpower-intensive fractions, such as sorting paper and plastic into sub-fractions instead of incineration. Crosses, however, have been set based on very rough estimates in the review.

3.2 Assessment of data for all fractions

The other issue examined in the review of the different waste fractions was an assessment of data sources in addition to the basic ISAG data. This review is included in the analysis of amount of time required to carry out a comprehensive mapping of the waste management field (see Chapter 6).

In order to calculate an LCA indicator it is necessary to be able to break down the mixed fractions into materials and analyse these between relevant treatment options. Only in this way will it be possible to link relevant LCA data to disposal of materials.

Problems of data especially concern the mixed fractions for incineration and landfilling, as these fractions stand for considerable quantities, and as no continuous studies of waste composition are made. This applies particularly to "mixed burnable", "non-burnable waste" and "construction and demolition waste", but also to "metals" that cannot be specified in more detail. For all mixed fractions extensive studies will be required to update the break-down into materials regularly.

Thus, ISAG statistics as they are today are not particularly suitable for stating anything on the fate of the different materials. This would require a more specific analysis of where the different materials end up upon disposal. This is done for a number of materials in the so-called material-flow statistics that have been prepared especially for a number of packaging materials, and a number of mass-flow analyses that have been prepared particularly for heavy metals. ISAG statistics may be used in particular for stating environmental impacts from management of waste fractions currently separated for reprocessing. If more detailed material flow/mass-flow analyses are available, it will also be possible to assess the environmental and resource-related potential from a change in waste management. Chapter 6 and Appendix B estimate the amount of time required to collect data for the individual waste fractions.

Table 3.1 Differences in environmental impacts in typical treatment of different waste fractions

Fraction (abbreviated text) Typical treatment	Energy (incl. contribution in subst.)	Resources*	Environmental impacts *				Landfilling *	Working environment *
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/hum		
Paper R/I	xx	X		x		x	x	xx
Glass R/L	x	X		x		x	x	
Plastic R/I	x	X		x	x	xx	x	x
Food waste R/I	x	X	Xx			x		?
Garden waste R/I	xx		Xx					
Metal R/L	xx	Xx		x		xx	x	
Tyres R/I	xx	Xx					x	
Concrete etc. R/L	x						x	
Asphalt R/L	x	X				?	xx	
C&D R/I/L	x	X				xx	xx	x
Wood R/I/L	xx					xx	x	
Soil etc. R/L	x					xx	xx	
Various recyclable L	xx	Xx				xx	x	
Health-care I	xx					x		
Burnable I/R	xx	Xx	xx	xx		x	xx	
Non-burnable L/R		Xx				x	xx	x
Sludge R/I/L			xx	x	x	xx	xx	
Screenings etc. L/R							xx	
Slag etc. R/L		Xx				xx	xx	
Asbestos L							xx	
Oil and chem. R/I	xx	Xx				xx		
WEEE R/L		Xx	xx			xx	xx	

Notes: *)
All resource consumption and environmental impacts are excl. contributions from energy consumption that are included in “energy”
xx: significant, x: less significant, nil: insignificant (in relation to other parameters for the fraction)
R: Recycling, I: Incineration, L: Landfilling

3.3 Conclusions on choice of indicators

Investigations indicate that as a minimum LCA-based indicators should and can include energy and resource consumption and landfill requirement. Toxicological issues are also important, but here, it may very demanding to provide LCA data for use as a waste indicator. For issues relating to working environment it is not yet possible to find sufficient data for analysing in the same way as for other parameters (see Chapter 2.3).

For the mixed group for incineration, several investigations have been carried out focusing on an analysis of contents. Here it will probably be possible to find data for preparation of a status of environmental impacts and resource consumption. In this way it will also partly be possible to divide the mixed fractions into materials and treatment options, which is necessary to calculate the three LCA-based indicators. For more detail, see Chapter 4.

Furthermore, the screening indicates that there may be great difficulties in finding data for all fractions. In Chapter 6, the extent of calculating LCA indicators for the total Danish waste management system is analysed.

4 Calculation method and assumptions

In this chapter the general assumptions for the calculation method for the indicators, resources, energy and landfill requirement are presented. In addition, data for the relevant treatment options for paper, glass and aluminium, serving as calculation examples, are reviewed. In Appendix C concrete data and assumptions for the indicator calculations are reviewed in more detail for each of the three examples.

4.1 Calculation method and assumptions for indicators

In the calculation of indicator values, waste quantities for the individual fraction and treatment option are multiplied by the related LCA impact factor. This is done for each of the three indicators.

The starting point for indicator calculations is quantitative data and indicator factors, both structured as in the below Table 4.1. The contents in each cell in the table with quantitative data (Table 5.1) are multiplied by the corresponding indicator factor (Table 4.3). The calculated values for each indicator are added together into a collective indicator value for the management of a material fraction. See the example in Table 4.1, where the quantity of glass packaging (in 1998), disposed of in different ways, is multiplied by the corresponding factors. The results for each of the four treatment options are added together and constitute the resource indicator value for waste management of glass. Indicator values for primary energy and landfill requirement are calculated in a similar way.

Table 4.1 Example of indicator calculation for glass packaging, 1998

	Landfill	Incineration with energy recovery	Reuse (bottles)	Recycling, material recovery
Paper and cardboard				
Packaging glass	3200 tonnes * 9.7 mPR per tonne = 31 PR	58800 tonnes * 9.7 mPR per tonne = 570 PR	57300 tonnes * 1.1 mPR per tonne = 63 PR	60300 tonnes * 6.7 mPR per tonne = 404 PR
Aluminium				

*) the sum for the example of glass packaging is a total of 1,068 PR which, for example, is the basis for resource consumption for glass packaging in Figure 5.10.

Indicator factors are based on life-cycle data for the individual material and on data for waste management of materials. In the following the most essential assumptions in the statement of quantitative data and for calculation of factors for the different fractions are summed up.

4.1.1 Material fractions and waste quantities

As stated in Chapter 2, the grouping of materials is not necessarily identical to waste fractions in the ISAG. The waste fraction “paper and cardboard” in the ISAG only covers paper and cardboard collected for recycling, whereas other paper is included in mixed fractions, for example “burnable waste”. For the material “paper” it will be necessary to make an estimate of total quantities of paper, including the amount of paper and cardboard included in the mixed waste fractions for incineration or landfilling.

In order to carry out calculations for all waste fractions it is necessary to break down the mixed waste fractions into material fractions. The composition of, for example, "burnable waste" thus must be broken down into material fractions such as: paper and cardboard, plastic, glass, different metals, compostable waste, etc. which to a certain extent can be done based on different data sources, and for some fractions based on estimates.

Thus part of the assessment of the extent of an indicator calculation for the entire waste management field is also to determine how it is possible to break down waste into material fractions on the basis of ISAG statistics and other accessible data. It must be anticipated that the break-down of mixed material fractions can only be carried out every five or ten years, so that in the intervening periods constant distributions of the fractions are used.

If indicators are to be used to follow developments from one year to the next, it is essential to ensure that indicators are sensitive to the differences that may be extracted from annual statistics (the ISAG and supplementary statistics), and not only reflect developments in total waste quantities.

For the three materials for which calculations have been carried out, it has been possible to provide data by combining ISAG statistics with other data sources (see Appendix C).

4.1.2 LCA data and allocation of recycled materials

The establishment of the three factors of resources, energy and landfill requirement is based on the fact that material taken out of circulation upon disposal must be substituted with virgin primary material (see Chapter 2.3). Thus, if 1 kg of glass is landfilled, 1 kg of virgin glass must be manufactured, which is a defendable consideration as long as society has a constant or increasing consumption, which is the case for paper and cardboard, glass and aluminium.

In addition, if it is a question of waste treatment of recycled materials, some of the value of this material will be lost in the previous use. To take this into account, the EDIP project’s loss of utility value (see Glossary) has been applied. Thus, for each material the extent to which the landfilled/incinerated material consists of recycled material has been assessed. For example, in Table 4.2 it is stated that paper and cardboard is a mixture of primary/recycled paper and cardboard – an estimated 50/50 distribution for the parts incinerated/landfilled. For the recycled part there has already been 20% loss of utility value, which is why in total there is only 90% loss of resources of paper consumption upon landfilling/incineration. For paper going to recycling, in return, a 20% loss of utility value is used in the calculation, which appears as a loss of 20% assigned to landfilling. A large part concerns filler materials in the paper.

Calculations are based on data from the EDIP project and the EDIP PC tool database. Unit processes are designed in general so that they add together resource consumption and environmental impact from the production of 1 kg of material. By considering the system from a waste disposal perspective it has therefore been necessary to adapt unit processes in cases where there is a material loss from recycling. For example, the unit process in the EDIP PC tool database /8/ shows that around 1.15 kg of paper is used for the production of 1 kg of recycled paper. This means that 1 kg of waste paper for recycling only gives 0.87 kg of recycled paper, and therefore an additional production of 0.13 kg primary paper is required before the system balances.

For all materials, statistics on quantities collected for recycling cannot indicate whether material collected is from recycled or primary materials. Therefore in most cases it has been necessary to calculate with estimated mixtures of primary and recycled materials.

For aluminium there is the special situation that upon incineration aluminium oxide is formed as a residue. Residues are around double the quantity incinerated, which is the reason for the value 190% for landfilling upon incineration of aluminium. This assumption derives from the EDIP project's data on incineration of aluminium. Subsequently the issue has been investigated, and it has appeared that most aluminium for incineration is not ignited, but just ends up in slag. Therefore, the value should be adjusted downwards in a subsequent indicator calculation for the entire waste management field. Similarly, the value of 10% for loss of utility value for glass, also deriving from the EDIP, may be too high and should be investigated in a later survey.

The specific percentages applied to the different materials and disposal processes are stated in Table 4.2 and explained in Appendix C. Table 4.3 shows factors deriving from the calculations. Values from the tables are illustrated in graphic form in Chapter 5, and results are commented on.

Table 4.2 Table with outline of unit processes and percentages used

	Landfill	Incineration with energy recovery	Reuse (bottles)	Recycling with material recovery
Paper and cardboard	Mixture of primary/recycled paper and cardboard (average 90% resource loss) 100% landfilling	Mixture of primary/recycled paper and cardboard (average 90% resource loss) 100% incineration of paper and cardboard (mix) with credit for coal saved	-	87.5% recycled paper (12.5% process loss) 32.5% primary paper mix (12.5+20%) 20% waste for landfill (loss of utility value)
Glass	Mixture of primary glass/reused glass (95% resource loss) 100% landfilling	Mixture of primary glass/reused glass (95% resource loss)	Process: only electr. and gas 2.5% loss of glass in washing	100% recycled glass 10% primary glass (10 % loss of utility value) 10% for landfill (loss of utility value)
Aluminium	100% primary aluminium 100% landfilling	100% primary aluminium 100% incineration aluminium Landfilling of 190% of the quantity incinerated.	-	95% recycled aluminium 5% primary aluminium (process loss) 9.5% for landfilling (process loss - AL-oxide)

4.2 New LCA data

When the calculation examples were made, it was necessary to a minor extent to update or provide new data.

The basic principle in the EDIP method used to calculate the LCA-based indicators is that items are made comparable by converting resource consumption and environmental impacts into person-equivalents (see Glossary). Normalised values thus achieved can then be multiplied by a weighting factor stating to which extent the resource consumption or the environmental impact in question is considered problematic.

Neither the EDIP project nor the EDIP PC tool database contains normalisation references or weighting factors for energy consumption or for landfill requirement for total waste quantities.

Table 4.3 Calculated factors (normalised)

Resource factors (mPR$_{WDK90}$ per tonne waste)	Landfilling	Incineration with energy recovery	Reuse (bottles)	Recycling with material recovery
Paper and cardboard	70	67	-	27
Glass	9.7	9.7	1.1	6.7
Aluminium	1582	1578	-	7.4

Energy factors (mPE$_{DK98}$ per tonne waste)	Landfilling	Incineration with energy recovery	Reuse	Recycling with material recovery
Paper and cardboard	168	106	-	84
Glass	61	61	7.5	48
Aluminium	950	884	-	56

Landfill factors (PE $_{DK98}$ per tonne waste)	Landfilling	Incineration with energy recovery	Reuse	Recycling with material recovery
Paper and cardboard	2.6	0.14	-	0.96
Glass	2.5	1.0	0.036	0.17
Aluminium	7.6	7.0	-	0.90

Units used are: mPR (milli-person-reserves), mPE (milli-person-equivalents) and PE (person-equivalents)

In the calculation of indicators, weighting is omitted of normalised data, as it would not make sense to aggregate them further. In particular it is not expedient to gather the factors resources and energy into one indicator, as the former also covers energy resources, meaning that an aggregation would count energy twice. Furthermore, a weighting would cause unnecessary discussion of the validity of indicators.

The lack of weighting means that indicators based on the three parameters are to be considered as a set of indicators, where much caution should be taken in making comparisons between the three indicators.

Another practical function of the normalisation of indicators is the fact that indicators may be presented on the same scale (and thus in the same figure), and that in some contexts it is easier to explain their meaning. If the purpose is just to obtain the same scale it would also be possible to index indicators. This would make it possible to put them on the same scale without a prior normalisation – but conversely normalisation would not prevent a subsequent indexation. In the presentation of results in Chapter 5, both approaches are used.

4.2.1 Normalised resource consumption

Resource consumption associated with the processes covered by the calculation is first stated in absolute figures in the unit tonnes. To allow for comparison and aggregation of consumption of several raw materials, a calculation method has been developed under the EDIP method, where the consumption of each single raw material is related to the size of the reserve.

In the EDIP method the term “weighted resource consumption” stated in person reserves is used (see Glossary). In reality this corresponds to normalising in relation to global reserves, for metals and minerals for which statements of global reserves are available.

For the renewable resources wood and water, the EDIP method uses local normalisation references based on an assessment of present consumption and supply perspective in a continuous depletion of reserves. For example, supply perspectives for wood and groundwater have been set at several hundred years, so such renewable resources will normally not dominate statements.

In Table 4.3 the total value for renewable and non-renewable resources is shown, but calculations are made so that results may be divided into the two groups by checking in the result tables of Appendix D (not translated).

For sand, gravel and other minerals extracted and used regionally, there are generally no statements of global reserves in the EDIP/the EDIP PC tool database, and therefore in this project it has been relevant to make an estimate for some of these resources: sand and gravel as well as sulphur in its pure form. For sand and gravel the study indicated that factors for these in comparison to other resources will be very insignificant. Considerations of this issue are stated in Appendix C.

4.2.2 Normalisation of energy consumption

Energy consumption for different processes cannot be found directly in the EDIP PC tool database, as energy consumption in the EDIP method is represented with associated resource consumption and environmental impacts. The primary energy consumption (see Glossary) for processes covered by the calculation can be calculated, however, on the basis of calorific value of energy resources used. In the conversion, a distinction has been made between renewable and non-renewable energy resources, and data for each single resource can be found in the background material. Only a total value has been shown in Table 4.3. The normalisation reference for energy consumption is calculated on the basis of Danish total primary energy consumption in 1998.

Concerning waste incineration it has been relevant to estimate the specific consequences of waste incineration for primary energy consumption at other energy supply plants supplying power and heating in Denmark. Considerations to this effect are part of the EDIP project, but it has been necessary to update data in connection with this project, as for some materials it may be a decisive parameter. At the same time, in recent years large changes have taken place in the area. Calculations and underlying considerations are discussed in Appendix C.

4.2.3 Landfill requirement

First, landfill requirement is stated in absolute figures in tonnes. In the EDIP there are four different categories of waste to landfill, normalised in relation to total waste quantities for each of the four waste categories. For the indicator calculations it has been decided to establish a collective landfill factor for all fractions as a whole. The normalisation reference for landfilling is set at total landfill requirement in Denmark in 1999.

It may seem unnecessary to state landfill requirement as an independent parameter, as total quantities landfilled already appear from waste statistics. However, another entity is calculated here, since landfill requirement is calculated in a life-cycle perspective. This means that, for example, landfilling of waste from extraction of raw materials is also included in landfill requirement.

A drawback of this indicator, however, is that landfilling of 1 kg is calculated with the same value whether the material landfilled is lead or glass. As long as in the LCA-context no weighting factor (based on impact factors) has been developed that can be used to state the degree of problems relating to landfilling of the different materials, it is beyond the scope of this trial to make a weighting. The EDIP project's division into four categories cannot solve this problem either, so we have chosen to just calculate one overall value for landfilling.

4.3 Calculation in practice

Environmental impacts and resource loss upon landfilling and alternative treatment options are calculated on the basis of EDIP data using a database programme that can calculate and manage the many intermediate results. For this purpose a programme has been used that has been developed by I/S ØkoAnalyse in connection with the project ”Environmental impacts in the family” /14/.

The calculation is carried out so that the different contributions to all parameters for environmental impact and resource use can be traced back to the different processes. In Appendix D (not translated) tables are presented of unit processes and waste quantities included in the calculations. Other tables show characterised and normalised values (see Glossary) for the three indicators, distributed on the three material fractions, both for kilos of waste and for total waste quantities.

After an assessment of data quality, an aggregation has been made of the selected factors stated in Table 4.3. This makes it possible to survey whether significant contributions are missing. Once the assessment has been made, it is possible to use the aggregated data for calculating resource, energy and the landfill factors for the different materials to be multiplied by the relevant waste quantities.

For the different forms of presentation of the results – including the two basically different models, a further calculation has been made of the calculated factors and amounts in a spreadsheet. Appendix D (not translated) presents data used and results, and it is also possible to find results broken down into energy resources and other resources, as well as renewable and non-renewable sources of energy.

5 Results of calculations

The calculation of indicator values for the three waste fractions: paper and cardboard, glass packaging and aluminium is based on factors for resources, energy and landfilling as calculated in Chapter 4 and Appendix C. Factors can by multiplied by the waste quantities for the different treatment options, thus giving indicator values. The calculation is described in more detail in Chapter 4, and results are presented and commented on below.

First, waste quantities behind indicator calculations are presented with results for both Model A and Model B (Chapter 5.1). The two forms of presentation are described in more detail in Chapter 1.

Then the calculation factors used in Model A are presented and commented on (Chapter 5.2). In Chapter 5.3 results for indicator calculations cf. Model A are presented.

Chapter 5.4 gives a short description of how to handle the calculation with waste data and indicator values forming the basis for the presentation Model B. In Model B focus is put on benefits from the actual waste management option compared to landfilling of all waste.

The two models are not only different in their way of presenting results, but also in contents of the presentation. In practice, the same basic data is used. The most significant difference in the data basis is that where Model A requires knowledge of total consumption of materials in society and waste treatment, Model B only requires specific knowledge of waste treatment and actual potential for recycling materials. This is explained in more detail in Chapter 5.4.

5.1 Waste quantities for calculations

The calculated factors for each material are multiplied by waste quantities distributed by treatment option. Waste quantities can be seen in Table 5.1. The basis for calculating quantities is explained in Chapter 4 and Appendix C.

Table 5.1 Waste fractions and treatment options in Denmark

Waste quantities in Denmark, distributed on treatment option, 1,000 tonnes	Landfilling	Incineration	Reuse	Recycling with material recovery
Paper and cardboard, 1998	86.3	557.7	-	640.5
Glass packaging*, 1998	3.2	58.8	57.3	60.3
Glass packaging*, 1995	11.3	58.6	53.9	51.5
Glass packaging*, 1991	20.0	37.4	42.8	49.8
Aluminium, 1994	5.0	9.8	-	30.9

* excl. deposit-return bottles

5.2 Presentation of calculation factors

Factors used for Model A in the calculation of indicators are shown in Table 4.3. Factors are further illustrated in the following figures. The data basis for calculations of the different factors for the three material fractions and relevant treatment options is provided in Appendix D (not translated).

5.2.1 Resource factors

Resource values are stated in PR – person reserves, expressing consumption related to known reserves of a given resource per person in the world (see Glossary). The calculation of the resource factor for a material fraction is based on a statement of resource factors for each individual resource used in the production of a material fraction. The contribution from each individual resource for each material fraction appears from Appendix D (not translated). Comments on the following figures are based on the underlying values.

Figure 5.1 shows that for paper the non-energy-related resource consumption has the highest weight, which is mainly due to consumption of the resource sulphur for the production of paper. The large weight attributed to sulphur in the statement is due to sulphur having a short supply perspective, when only traditionally available sources are taken into account. However, large sulphur resources are bound in fossil fuels, and they are increasingly exploited today. Therefore, it may be argued that the resource statement for sulphur should give a lower value, taking such sources into account (see Appendix C). In the EDIP project, the normalisation of sulphur has been disregarded (setting the value = 0), which does not seem correct either. The example thus indicates that the LCA methodology is still under development.

For glass packaging, by contrast, energy-generating materials have the highest weight (see Figure 5.2). The result is that from a resource perspective the difference between recycling and landfilling glass is not very large, since there is considerable energy consumption associated with glass remelting, whereas there is large benefit from reuse of glass packaging without remelting. In terms of resources (and also energy) large benefits can thus be obtained from reusing a large amount directly as glass packaging compared to recycling glass from cullet.

Total resource consumption associated with the treatment of 1 tonne of aluminium appears from Figure 5.3. Upon recycling or incineration secondary materials are generated, thus saving virgin materials, aluminium and sand/gravel respectively. As the figure and Table 4.3 shows, resource savings from incineration of aluminium are insignificant compared to resource consumption for production of virgin aluminium for substitution of what was lost. However, this is based on the assumption of aluminium being completely incinerated (see Appendix C).

For resource factors (see Figures 5.1 to 5.3) it is evident that aluminium is markedly different from the two other material fractions, as the factor per tonne is 30 times higher than for paper and 150 times higher than for glass. The reason is that the use of bauxite for aluminium production has a high weight despite a long supply perspective for bauxite. The use of energy-generating materials only contributes little to the total resource consumption associated with the production of aluminium, as hydropower is used extensively, weighing very little in terms of resources (see Figure 5.3). The contribution from the different raw materials to the resource factors can be seen in Appendix D (not translated). Thus, it is also possible to break down contributions between renewable and non-renewable resources, as in Figures 5.4 to 5.6. In general, renewable resources only have low weight, which is due to the statement method (see Glossary).

Figure 5.1
Total resource consumption associated with treatment of **1 tonne of paper** and production of substitute material for different waste treatment options.

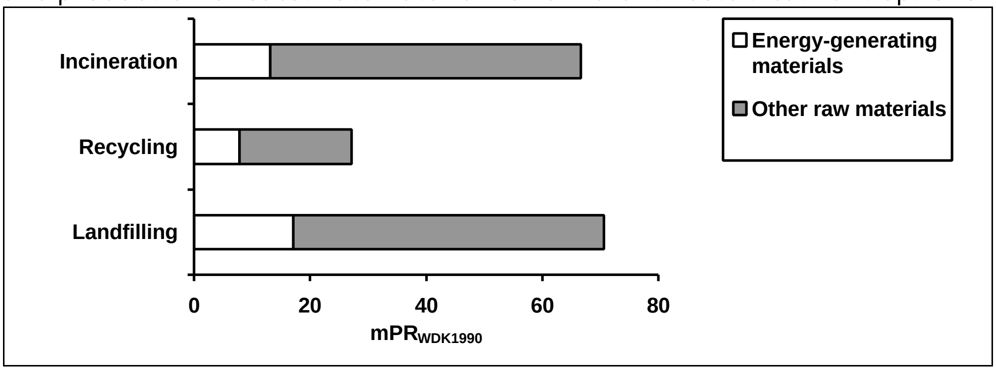


Figure 5.2
Total resource consumption associated with treatment of **1 tonne of glass** and production of substitute material for different waste treatment options.

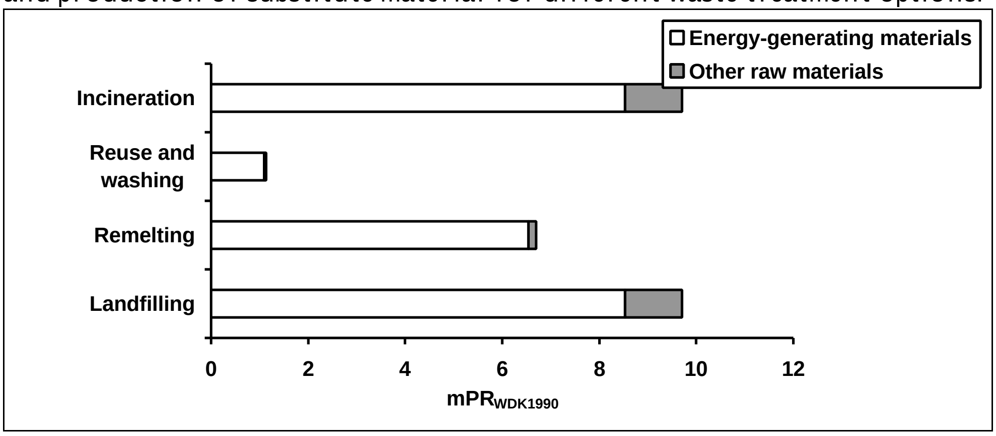
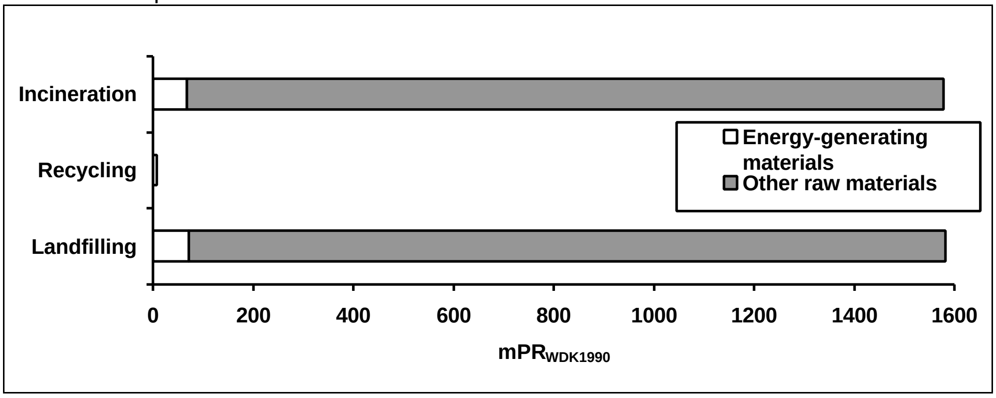


Figure 5.3
Total resource consumption associated with treatment of **1 tonne of aluminium** and production of substitute material for different waste treatment options.



5.2.2 Energy factors

The energy factor expresses how much net primary energy (see Glossary) is used for different treatments of the three waste fractions. The unit here is mPE_{DK98} per 1,000 tonnes of material. Primary energy consumption in Denmark in 1998 was 160 GJ per person, and one mPE therefore equals 160 MJ. Energy consumption as an indicator is particularly applicable as a total measurement of environmental impacts from use of energy, and in contrast to the resource factor, it weighs renewable and non-renewable resources against each other. Figures 5.4 to 5.6 therefore state which part of energy consumption derives from renewable and which part derives from non-renewable energy resources.

Virgin paper is primarily produced with renewable energy resources: wood and hydropower. Figure 5.4 shows that paper upon incineration substitutes non-renewable energy resources. Stated in person-equivalents the result upon incineration of paper is a primary energy consumption in the form of renewable energy resources of over 100 mPE/tonne, which is slightly more than upon recycling of paper.

Thus, the calculation shows that despite energy recovery upon waste incineration there is a benefit in terms of energy from paper recycling, even though this benefit should be compared to the larger consumption of non-renewable energy sources upon recycling. Energy consumption upon recycling of paper, however, is in the range of 50% of energy consumption of production of virgin paper.

Figure 5.4
Total primary energy consumption associated with treatment of **1 tonne of paper** for different waste management options. Note that primary energy consumption is calculated by deducting the left-hand side of the bar (the negative part) from the right-hand side. Thus, incineration of paper rates worse in terms of energy than recycling, and better than landfilling.

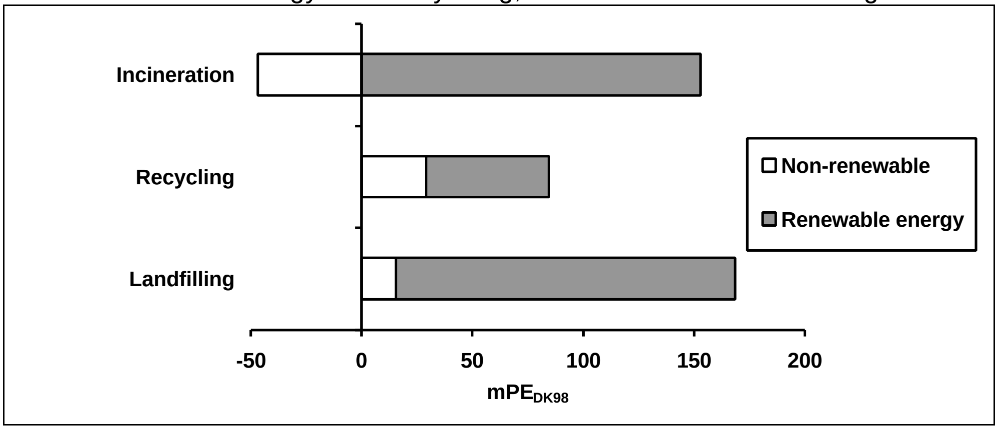


Figure 5.5
Total primary energy consumption associated with treatment of **1 tonne of glass packaging** for different waste management options.

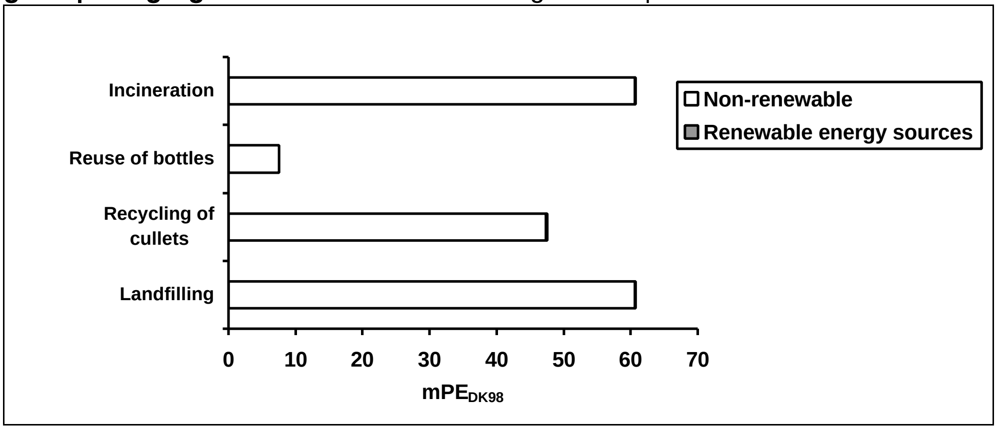
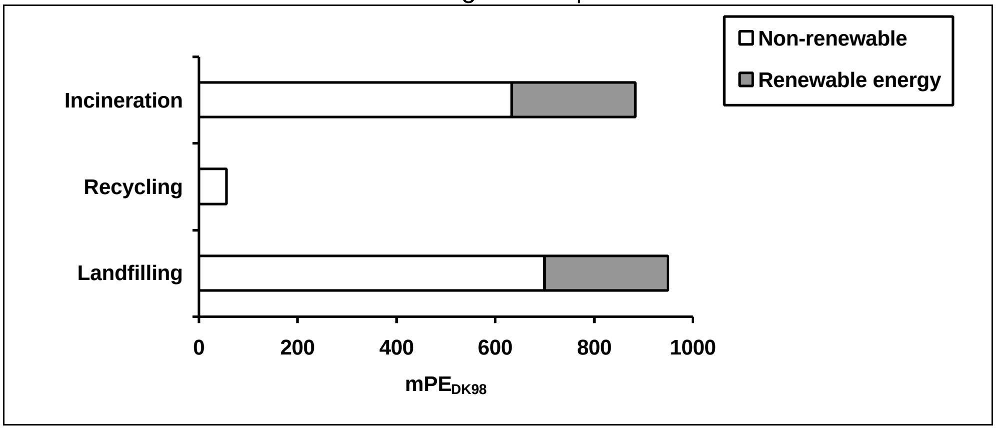


Figure 5.5 shows that for glass packaging primary energy consumption upon reuse of glass is markedly lower than upon remelting of cullet. However, remelting is slightly better than landfilling, if only primary energy consumption is taken into account.

Figure 5.6 shows that primary energy consumption upon recycling of aluminium is considerably lower than for other waste management options – which is not surprising. It is also seen that even if it is assumed that aluminium burns upon incineration (see Appendix C), the energy benefit gained is relatively small compared to the benefit from recycling.

Figure 5.6
Total primary energy consumption associated with treatment of **1 tonne of aluminium** for different waste management options.



5.2.3 Landfill factors

The landfill factor expresses how much waste for landfilling is generated upon different management options for the three waste fractions. The unit is PE_{DK98} per 1,000 tonnes of material. The quantity of waste landfilled in Denmark in 1998 was 403 kg/capita, so one PE of waste for landfilling = 403 kg.

Figure 5.7 shows that upon landfilling of paper, the amount is just above the 2.5 PE that paper for landfilling constitutes by itself. This is due to the fact that some waste is landfilled in connection with production of paper. Upon recycling of paper, landfilling of waste paper from the recycling process takes place – particularly filler material from paper often ends up in sludge for landfilling. Incineration of paper generates some slag, which is mainly due to the contents of unburnable filler material in the paper. At the same time, incineration also gives savings in primary energy such as coal, and thus saves waste for landfilling from extraction and combustion of coal. Quantities are smaller for incineration of paper compared to recycling mainly due to the fact that a very large part of slag from incineration is used for building and construction purposes, thus counting as recycling and not taking up space for landfilling.

For glass (Figure 5.8) just about the same quantity is landfilled as for glass for landfilling by itself – so there is no significant contribution in connection with the production of glass. Furthermore, the quantity for landfilling upon incineration constitutes 40% of total quantities, as 60% of slag from incineration is recycled for building and construction purposes. Recycling and reuse cause only a small amount for landfilling.

Figure 5.9 shows landfilling of waste from the different waste management options for aluminium. In addition to the quantity landfilled virgin aluminium must be produced, causing very large quantities for landfilling. Also upon incineration, aluminium will have to be substituted, and considerable quantities of slag are generated. Slag quantities are around double the quantity of aluminium, under the assumption that incineration is complete (see Appendix C). This is due to the fact that aluminium oxide is generated upon incineration. In return, around 60% of slag is recycled as backfilling. The result is that for landfill requirement there is no significant difference between direct landfilling and incineration of aluminium. Only upon recycling is a substantial reduction in landfill requirement achieved.

Figure 5.7
Total landfill requirement associated with treatment of **1 tonne of paper** and production of substitute material for different waste treatment options.

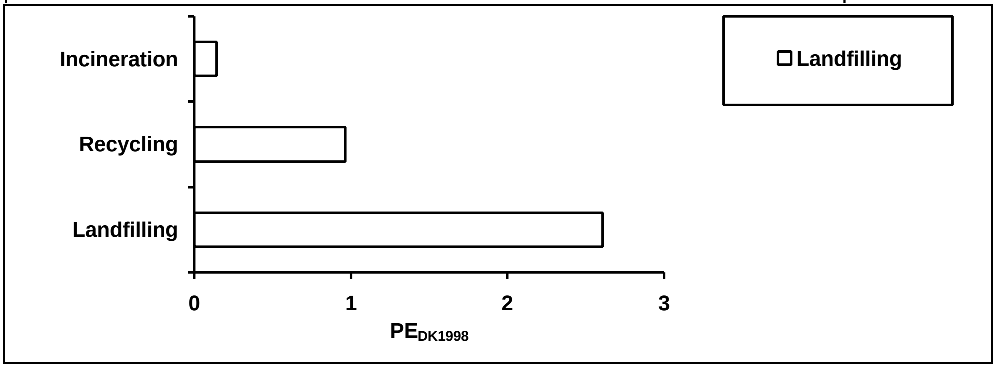


Figure 5.8
Total net landfill requirement associated with treatment of **1 tonne of glass** and production of substitute material for different waste treatment options.

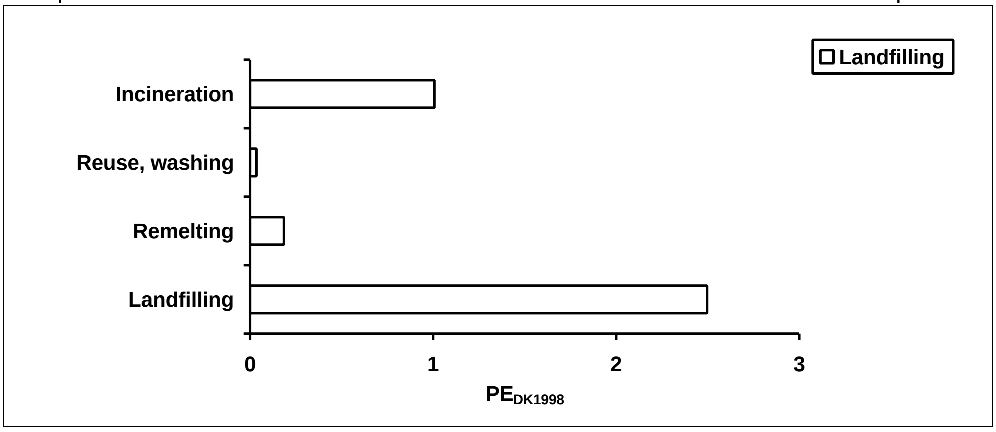
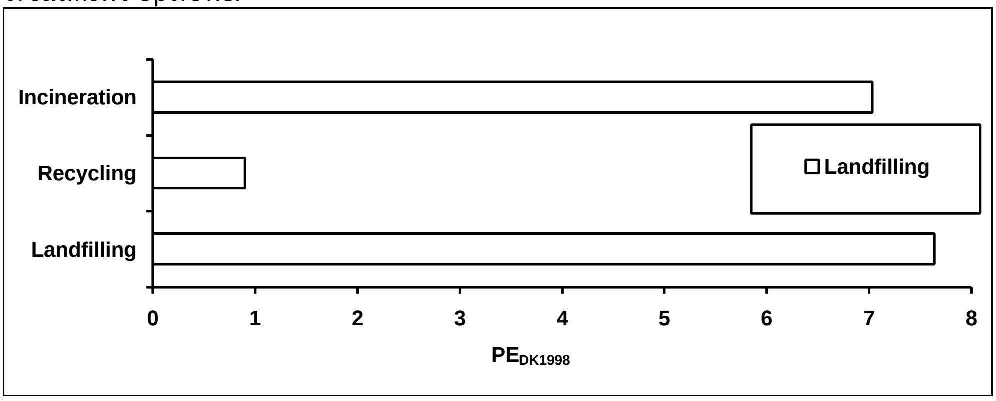


Figure 5.9
Total net landfill requirement associated with treatment of **1 tonne of aluminium** and production of substitute material for different waste treatment options.



5.2.4 Differences between factors for the three materials

There are significant differences for both energy and resource factors between recycling and other treatment of aluminium. For paper just above half of the energy and resource consumption is saved upon recycling compared to landfilling. For glass it is seen that even if materials are recovered, there is considerable resource and energy consumption in the range of 50-70% of consumption, if materials are landfilled. For energy factors the difference between aluminium and the other materials is less marked, but still significant (see Figures 5.4 to 5.6).

Naturally, the situation is different for the landfill factor, where there is a significant effect of recycling (see Figures 5.7 to 5.9). The landfill factor is around three times higher for aluminium for landfilling than for glass for landfilling. The difference is due to the production of primary aluminium that generates considerable quantities of waste included in the calculation. For paper, landfilling from recycling is larger than landfilling from incineration, as filler material in paper is landfilled upon recycling. Furthermore, incineration of paper leads to savings in coal, and thus there is less waste for landfilling from coal extraction and combustion.

For aluminium the landfill factor is only slightly lower upon incineration than upon landfilling, as part of aluminium oxidises upon incineration, thus generating considerable waste quantities (see Appendix C). It may rightly be argued that similar oxidation will take place in the long-term upon landfilling. But in order to simplify calculations, long-term changes of materials upon landfilling have not been taken into account. Recycling of slag from incineration for backfilling etc. constitutes 60% of slag and fly ash generated /40/, which has been taken into account in calculations.

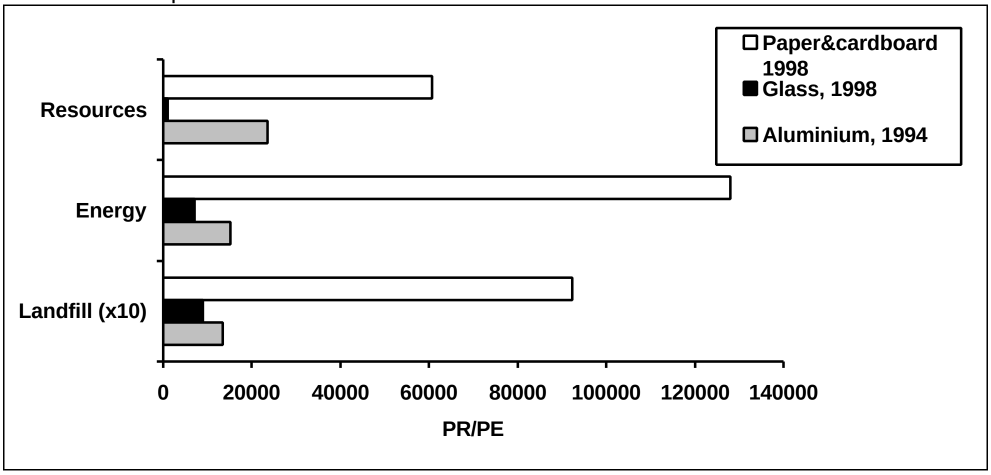
5.3 Indicators for total impact from waste (Model A)

In the calculation of indicator values, factors for the three waste fractions (see Table 4.3) are multiplied by waste quantities for the different treatment options (see Table 5.1). The calculation is described in more detail in Chapter 4. Results are presented and commented on below.

As seen from Figure 5.10, indicator values give slightly different pictures of the relative importance in terms of waste of material fractions upon the relevant waste treatment option. It is seen that the three indicators give significantly different results that supplement each other.

For reasons of simplification, in this and the other figures on indicator values no distinction has been made between resources in energy resources and other resources. Neither has a distinction been made between primary energy in renewable and non-renewable sources. The distinction can be found in Figures 5.1 to 5.6, or in Appendix D, stating detailed results (not translated).

Figure 5.10
Consumption of resources, energy and landfill requirement from treatment of waste and production of substitute materials.

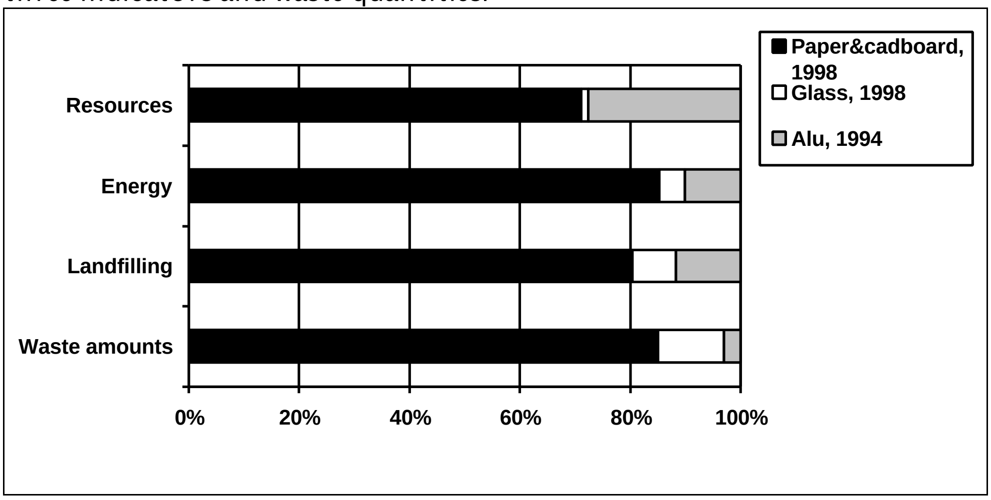


The following units have been used: Resource consumption: PR_{WDK90} ,Energy consumption: PE_{DK98} , landfill requirement: $PE_{waste\ DK98}$. Values for landfill requirement must be multiplied by 10. Note that the three indicators have only been shown on the same figure for practical reasons. Each indicator should be studied separately.

Results can also be illustrated relatively, as in Figure 5.11, where the three materials have been interrelated. The figure shows how much each material fraction makes up of total indicator value. Figure 5.11 shows that despite the far smaller waste quantities compared to the two other material fractions, aluminium gives a considerable contribution in terms of resource consumption. Paper gives the most significant contribution to energy, which may not be surprising. Paper also gives a significant contribution to resource consumption, this is mainly due to the large weight in terms of resources that has been attributed to sulphur in the statement. This is discussed in Chapter 5.2.1.

Figure 5.11 gives an idea of the focus of the three indicators, and it shows that waste quantities by themselves give a markedly different picture. Thus, there may be good reasons to operate with several indicators to gain an adequate picture of the waste management situation.

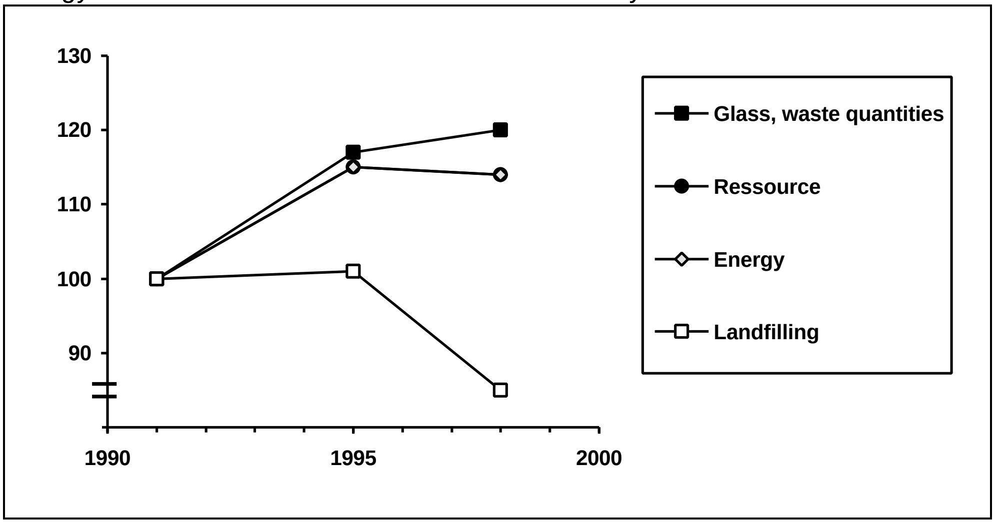
Figure 5.11
Relative contribution of the three waste fractions studied, in relation to the three indicators and waste quantities.



As one of the purposes of indicators is to illustrate effects from initiatives in the waste management field, it is important that indicators can be used to follow developments.

Figure 5.12 shows waste quantities and the three indicators for glass stated for 1991, 1995 and 1998 and indexed on 1991. Total quantities of glass waste in the period increased by around 20%, and similarly energy and resource indicators increased by 10-15%. The lower increase in indicators is the result of increased recycling, but results show that total resource and energy consumption associated with the use of glass increased in the period despite initiatives in the waste management field. The landfill factor, by contrast, decreased by 20%, which reflects the fact that glass for incineration is partly recycled together with slag from the incineration plants.

Figure 5.12 Developments in waste quantities and the three indicators for glass in 1991, 1995 and 1998, with 1991 = index 100. Note that resource and energy indicators are coincidental for the three years.



For aluminium, a detailed material flow analysis is only available for 1994 (see Appendix C), and therefore it is not possible to make a statement where developments are followed, for example from 1991 to 1998. It is likely that increased use of civic amenity sites and schemes for collection of waste electronic and electrical equipment have led to an increase in collection of aluminium, but it is also likely that waste quantities have increased. However, without an update of the available mass-flow analysis it is not possible to reflect this development.

The trial shows that it is very relevant to include metals, if the life-cycle-based indicators are to be applied to the entire waste management field. For the indicator for resource consumption a number of other metals will probably contribute considerably, similar to aluminium. In the normalisation of world resources for the different metals, even metals consumed in small amounts, but having a low rate of recycling, will contribute significantly to the weighted resource consumption. For energy consumption, aluminium weighs heavily, and other metals – apart from iron and steel – will probably contribute significantly less than aluminium.

5.4 Indicators with focus on savings realised (Model B)

The difference between presentations A and B is primarily in the focus of the presentation. Whereas A focuses on total waste quantities, B focuses on savings realised in resources, energy consumption and landfilling upon the waste treatment option in question compared to 100% landfilling.

The basic calculation principles for life-cycle data and quantitative data are similar for the two models. In principle, indicator values for presentation Model B can be calculated on the basis of two scenarios, one of which is the calculation for Model A, showing indicator values for the waste management option in question. The second waste treatment scenario is calculated, assuming that all waste is landfilled. Indicator values for the presentation of Model B are then found by calculating the difference between the two scenarios. This results in indicator values for resource, energy and landfill advantages realised upon the current waste management compared to 100% landfilling.

Finally, a third scenario can be added where a full optimisation of waste management is assumed. The difference between this scenario and current waste management shows the potential from optimising waste management. This is also included in the presentation Model B below.

In the calculation, however, the procedure has been simplified by converting factors from Model A (Table 5.1) into a set of factors for Model B (Table 5.2). The conversion has been made by calculating the difference between landfilling and other options for each individual factor and material. Basic data is thus similar to data described for Model A. The column for landfilling in Table 5.2 is 0 for all fields, and positive or zero for other treatment options. It shows that landfilling is always the poorest alternative in the examples calculated.

Table 5.2
Calculated factors, Model B. Savings from different treatment options compared to landfilling.

RESOURCE FACTORS (mPR, $_{wdk90}$ per tonne waste)	Landfilling	Incineration with energy recovery	Reuse (bottles)	Recycling, material recovery
Paper, cardboard	0	3	-	43
Glass	0	0	9	3
Aluminium	0	4	-	1575

ENERGY FACTORS (mPE $_{dk98}$ per tonne waste)	Landfilling	Incineration with energy recovery	Reuse	Recycling, material recovery
Paper, cardboard	0	62	-	84
Glass	0	0	54	13
Aluminium	0	66	-	950

LANDFILL FACTORS (PE $_{dk98}$ per tonne waste)	Landfilling	Incineration with energy recovery	Reuse	Recycling, material recovery
Paper, cardboard	0	2,5	-	1,6
Glass	0	1,5	2,5	2,3
Aluminium	0	0,6	-	6,7

Units used::
mPR (milli person reserves), mPE (milli person equivalents), and PE (person equivalents)

The presentation of data in Model B matches well with the data found for waste management in waste statistics. It first and foremost shows indicator values for waste collected for reprocessing, whereas waste led to landfill does not contribute to the indicator. If the potential from an optimisation of waste management is to be calculated, data must be supplemented from other statistics than the waste statistics. In addition, it is necessary to assess how much material it is possible to collect from a waste fraction.
This is discussed in the following chapters.

5.4.1 Value of recycled materials and potential savings

Below the principles of the current optimal recycling and how they can be calculated in an indicator calculation are discussed.

For example, for aluminium normal practice in connection with recycling is that a number of aluminium alloys are mixed, and that upon recycling almost exclusively high-alloy cast aluminium is produced. Opportunities for future recycling of this cast aluminium will be significantly more limited than recycling of low-alloy aluminium types. The latter constitutes the major part of aluminium disposed of today through recycling. Thus, in a long-term perspective it will be optimal to keep aluminium alloys separate in the recycling process.

In the recycling process some aluminium oxidises and is landfilled in the form of aluminium oxide. In some Norwegian melting works treatment and recycling of this aluminium oxide takes place. In relation to resource savings this process will be optimal compared to the more usual melting process. The optimal recycling thus differs from the form of recycling that is generally used today.

If a detailed analysis is to be made for each disposal option of the best available technique, the task of data collection and assessment would be very extensive. Therefore, it is proposed that the definition of the optimal form of recycling is handled more pragmatically, so that for example in relation to aluminium average data from European recycling industries is used, provided by the EDIP PC tool database. In addition to simplifying data collection this has the advantage of avoiding very extensive explanations of calculation assumptions.

When direct recycling as a metal is compared to energy recovery upon incineration or recycling of aluminium oxide in the form of slag from waste incineration, recycling as a metal will be the optimal choice in all circumstances.

In relation to current recycling the problem is more than the impacts associated with recycling; these can be determined in relation to the actual recycling (to the extent that data is available). The problem is also to determine what is actually substituted upon recycling, and what quality (value) to attribute to the recycled material.

The starting point is that we wish to make a calculation covering all material recovered. How would all the aluminium produced today from recycling have been produced if there had been no recycling? And how would the district heating provided today from waste incineration have been generated if there had been no energy recovery from incineration?

We actually do not know this, and particularly in the field of energy, developments will not only be governed by market economy mechanisms. Similar to the approach used for determining the optimal form of recycling we will therefore use a pragmatic approach, based on average considerations. However, for heating generation from incineration we have carried out a more detailed study in Appendix C. This means for the example of aluminium that data is used representing in the EDIP PC tool database the average for aluminium produced in Europe. For power and heating generated in Denmark we have made a specific assessment of the impact from incineration of waste at Danish waste incineration plants on consumption of coal.

5.4.2 Potential savings from optimisation of waste management

The indicators in calculation Model B have the purpose of showing realised and potential savings in relation to the three parameters. Realised savings can be based on quite reliable quantitative data and are altogether not very debatable, whereas it is necessary to make more assumptions for potential savings.

In the calculation examples used, potential savings have been calculated as follows:

For paper and cardboard a theoretical potential has been used, where 87% of total paper consumption is recycled in a way similar to present recycling of paper and cardboard. It will not be possible to reach a higher rate of collection, as some paper is tissue ending up in domestic waste or in the sewer. In waste statistics /39/ the realistic potential of recycling of paper is assessed at 80%. See also Appendix C.

Furthermore, it has been taken into account that paper material loses utility value upon recycling. Thus the potential is an expression of theoretical maximum limit. Further savings can be realised if paper and cardboard are reused directly, but this will probably only be practicable for a small part of transport packaging, and the amount of paper and cardboard directly that is reusable has not been estimated.

For glass packaging two theoretical potentials have been stated. One level presupposes the recycling by washing glass which is reused today, whereas the rest is recovered by remelting. However, there will probably be a minor part of glass packaging that cannot be collected for recycling because of different kinds of contamination, so 100% recycling will be unachievable in practice. It should be noted that reuse of bottles for beer and soft drinks is not included in the calculation, which covers other forms of glass packaging.

At the other potential level it is assumed that 100% of glass waste can be potentially reused as bottle / glass packaging – including glass currently remelted. To achieve such a high degree of reuse will probably require significant changes in the use of glass for packaging as well as a collection system where glass is not broken (for example standard packaging types as known from beer and soft drinks). Today, a significant part is broken upon collection. Thus, the potential is theoretical, but it is not possible offhand to assess the extent of a realistic potential.

For aluminium 100% recovery is assumed in the calculation. In the recycling process there will be a loss in the range of 5%, which has been taken into account in this process. Thus, virgin aluminium will be added on a continuous basis, and it will be possible to have a cycle without losses due to material deterioration upon recycling. In practice, with the present use of aluminium for packaging it will be difficult (or impossible) to achieve such high rates of recycling, as part of it will end up in domestic waste.

Realised and theoretical potential savings in resources, energy and landfill requirement are shown in Figures 5.13 to 5.15. For comparison, realised and potential savings stated in waste quantities are shown in Figure 5.16.

Compared to paper and cardboard, and aluminium, realised savings from recycling of glass are relatively modest both in terms of resources and energy. It should be noted that reuse of bottles for beer and soft drinks is not included in the calculation. However, in terms of energy there is a potential for savings, if glass packaging is reused directly.

Figure 5.13
Realised savings from present waste management and possible potentials for savings in **resource consumption** associated with treatment of the three material fractions. "potential 2" is reuse of all glass packaging by washing.

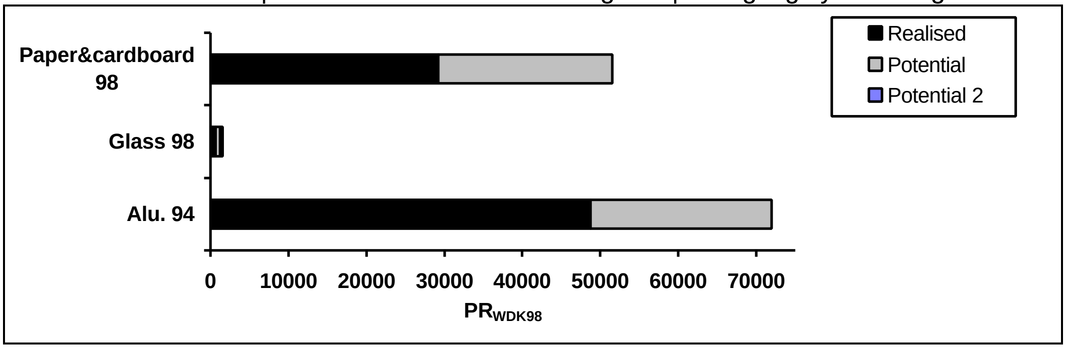


Figure 5.14
Realised savings from current waste management and possible potentials for savings in **primary energy consumption** associated with treatment of the three material fractions. "Potential 2" is reuse of all glass packaging by washing.

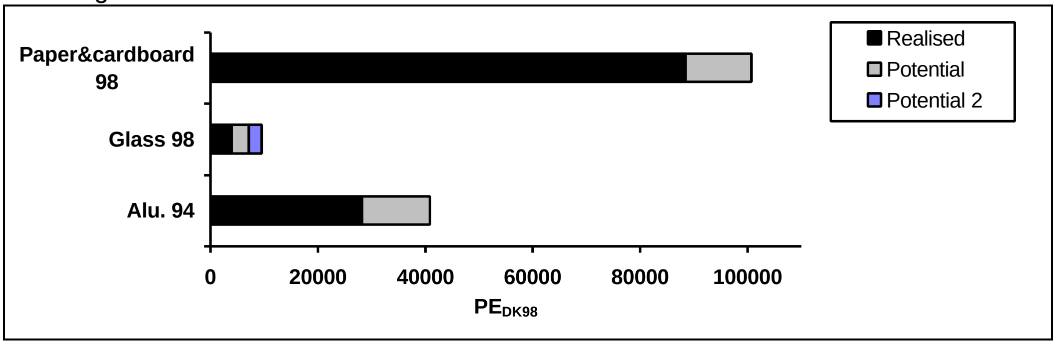


Figure 5.15
Realised savings from current waste management and possible potentials for savings in **landfill requirement** associated with treatment of the three material fractions. "Potential 2" is reuse of all glass packaging by washing. Note that the potential of increased recycling of paper and cardboard gives increased landfill requirement for residuals from recycling (the negative part of the bar). See also Figure 5.4.

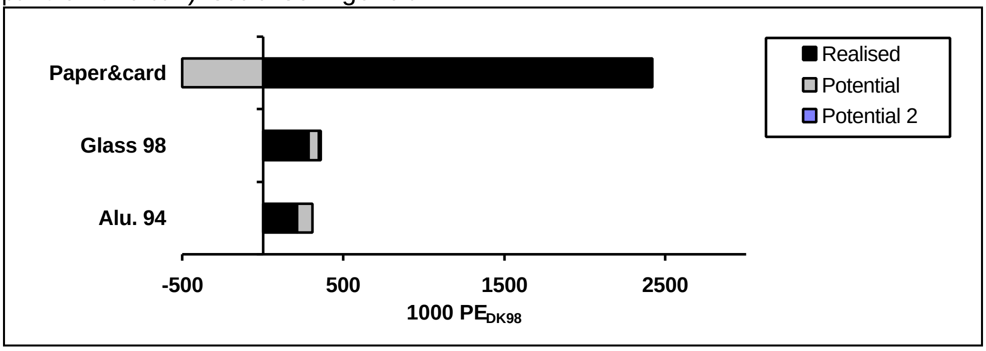


Figure 5.16
Realised savings from present waste management and possible potentials for savings stated as **waste quantities** associated with treatment of the three material fractions. "Potential 2" is reuse of all glass packaging by washing.

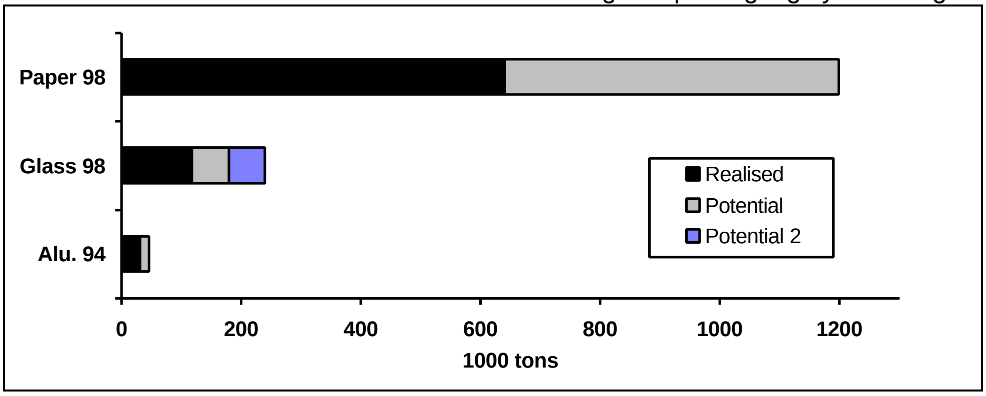
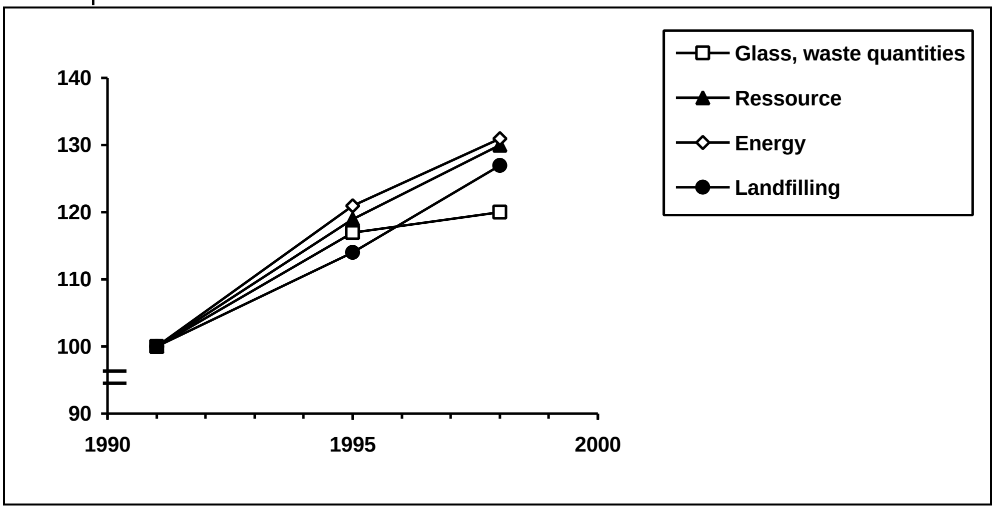


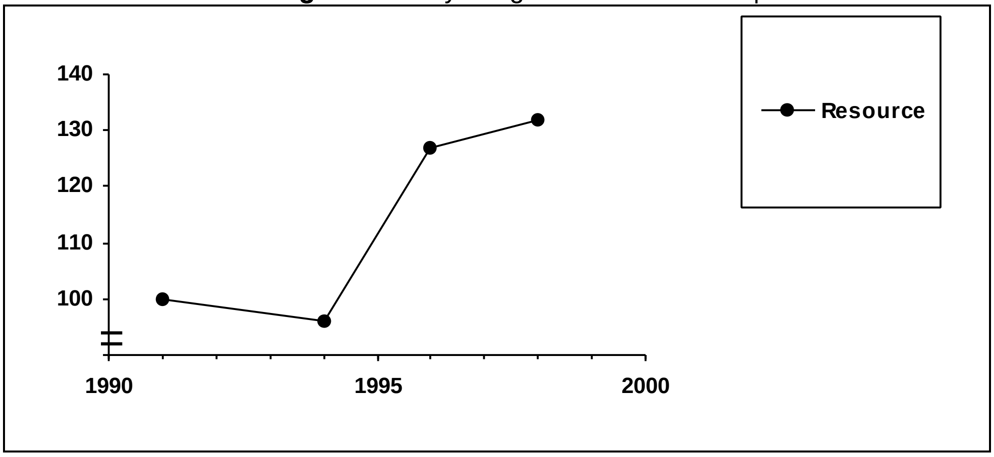
Figure 5.17 shows developments in realised savings associated with disposal of glass waste in the period 1991-1998. The figure is based only on calculated factors and data from the ISAG. The pattern seen is a reflection of the pattern seen in Figure 5.12, as here total savings to some extent are a function of larger waste quantities. However, there is also an effect from improved treatment options, as savings measured by the three indicators increase more than waste quantities.

Figure 5.17
Realised savings from recycling of glass in the period 1991-1998 shown as indexed values for the three indicators compared to developments in glass waste quantities.



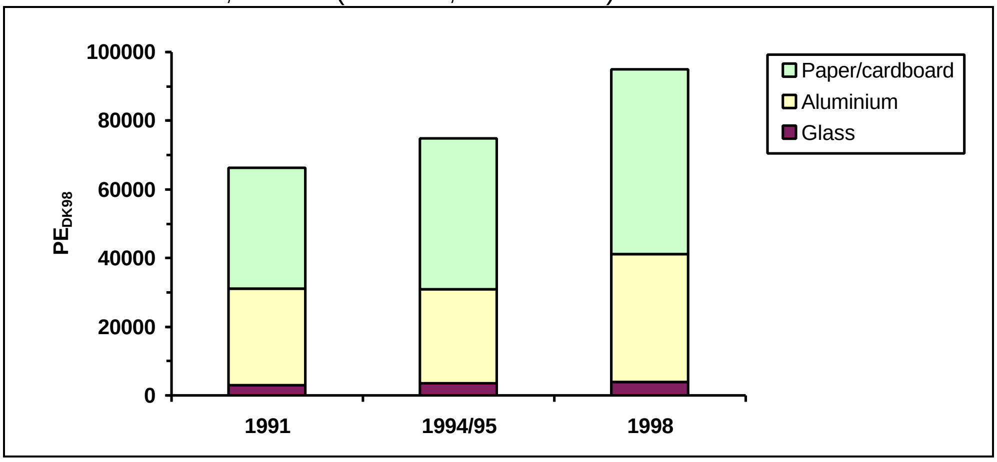
For aluminium, developments in realised savings are shown in Figure 5.18. In Appendix C a method is described – based on information from Statistics Denmark – for estimating amounts of aluminium treated upon recycling. In order to test whether the method is reliable and actually visualises developments, collected amounts have been calculated for a number of years and are shown as indexed values in Figure 5.18. Only developments in resource savings have been calculated.

Figure 5.18
Realised **resource savings** from recycling aluminium in the period 1991-1998.



To illustrate how the different material fractions contribute to total savings, Figure 5.19 shows data for 1991, 1995 and 1998 for energy savings realised from the actual waste treatment compared to 100% landfilling of waste. Overall, savings have increased by around 40% through the 90s.

Figure 5.19
Realised **energy savings** from recycling of paper and cardboard, glass and aluminium in 1991, 1994/95 (Alu:1994, others 1995) and 1998.



5.4.3 Conclusion

The different ways of presenting indicators focus on different aspects of waste treatment. One of the essential arguments for preferring presentation B to presentation A is the possibility of collecting and updating data. This is discussed in Chapter 6.

6 Use of indicators in the entire waste management field

The assessment of the possibilities of using the proposed indicators in the entire waste management field covers the following elements:

- Time required to calculate the three life-cycle-based factors
- Time required to estimate amounts of the different material fractions
- Time required for annual calculation of indicators
- Overall assessment of scope of update.

Decisive for the amount of time required is whether the calculation of indicators uses data for the entire material consumption and waste treatment in society (Model A), or whether only data for quantities actually recycled or incinerated is used (e.g. calculation of realised savings Model B), supplemented by data for relevant potentials for recycling.

Appendix B discusses assumptions, and below an overall assessment of amount of time required for the three relevant alternatives is given:

I. Status of the entire waste management field (Model A)
II. First statement of indicator calculation for realised savings and potentials (Model B) without previous status (I)
III. Annual updating of Model B, whether on the basis of I or II.

6.1.1 Time required to calculated life-cycle-based factors

Provision of data for calculation of life-cycle-based factors must primarily take place the first time the calculation is carried out. In the current annual statements of realised savings it would not be expedient to update factors, as this would only result in indicators reflecting changes in factors rather than developments in waste management.

In the assessment of amount of time required to provide life-cycle data for materials and treatment options to be included in the status, the point of departure is an assessment of the number of materials and waste treatment options in question. In principle, most materials can be included in waste. However, some materials will be excluded, as they are only present in insignificant quantities.

If it is assumed that within each of the three fractions of metals, plastic, and oil and chemical waste statements are made for seven materials, and within each of the other 12 fractions listed in Chapter 6.1 statements are made for two significant materials, there will be around 45 materials that may be handled in two to four different ways each. This gives a total of 90-180 life-cycle-based data sets. Of these, however, many will be relatively similar, such as incineration of different types of plastic with the same calorific value.

A very large part of this LCA data is already available, even if updates may be necessary. Assuming that 10-20 data sets are non-existent and that 10-20 need updating before being applicable, these will require the largest amount of work with calculation of life-cycle-based indicators.

It should be noted in this context that for the proposed indicators it is merely a matter of providing data for resource consumption from which energy consumption can be derived, as well as data for assessment of landfill requirements in the entire life-cycle of the material. This limits the task of providing relevant data considerably. It is assessed that the work of providing LCA data can be done in around 2 man-months. The work must be done whether it is chosen to make the comprehensive statement (Model A) or an indicator calculation of realised savings (Model B). In the annual update of indicator calculations it should be expected that around 0.5 man-months will be needed for updating LCA data.

6.2 Time required to estimate quantities of material fractions

Time required to set up general principles for calculation of waste quantities of the different material fractions, as well as possibilities of doing this, are explained in Appendix B and discussed briefly below.

Mixed waste fractions such as “domestic waste” are made up of a number of material fractions and will be represented in the calculation of these materials. This means that for each material there will also be an assessment of how large a proportion, for example, is incinerated with domestic waste or bulky waste.

It is estimated that a distinction should be made between the following material fractions:

- Paper and cardboard
- Glass – divided into glass packaging and “other glass”
- Plastic – divided into PE, PVC, PS, PP, PET and ”other plastic”
- Metal – divided into iron and steel, stainless steel, aluminium, copper, zinc and lead
- Oil and chemical waste, if necessary divided into main fractions
- Automobile rubber
- Concrete
- Tiles
- Asphalt
- Wood – clean and pressure impregnated
- Other building materials – divided into, for example, insulation materials, plasterboard and roofing (excl. tiles)
- Food waste/other organic
- Garden waste
- Soil, gravel and stone
- Other materials – for example ceramics, rubber (excl. automobile rubber) and textiles.

6.2.1 Scope of status

Information on data sources for quantitative data is discussed in Appendix B, including an outline in Table 2.1. The table has not been included in the main report, as for some aspects it is incomplete. For each material fraction data sources are stated and an assessment of uncertainty of data. Uncertainties are a rough estimate made by the authors to the best of their ability. As the largest uncertainties are associated with non-recycled waste quantities, it is further stated how large a proportion of total waste is collected for recycling. As it is seen from the table, for some materials it will be necessary to supplement information from the ISAG and material flow statistics on total quantities disposed of. In addition, in particular for metals, new mass-flow statistics are available that can also be applied. For a study to be applicable, it must have been carried out within the last five years.

The preparation of statuses will probably account for the largest part of time required to set up total calculation principles and provision of quantitative data to conduct the first calculation of indicators. Total amount of time required to update statuses has been assessed in Appendix B at 12-30 man-months. In the calculation some time can be saved if existing mass-flow analyses are used for some of the metals from 1994, or from any similar updated studies. With this assumption, the amount of time required to set up the total calculation principle will be in the range of 10-20 man-months.

An alternative to an extensive status can be to calculate realised savings for the entire waste management field, as well as calculation of realistic potentials for further optimisation of waste management (Model B). Initially, setting up this model will in particular require collection of data focusing on present incineration or recycling of materials. To this should be added an assessment of realistic potential savings. This is assessed to require 3-5 man-months – depending on number of materials assessed to be realistic for recycling.

6.2.2 Annual calculation of indicators

Annual statements of realised savings (Model B) can be carried out with an input of about one man-month for data collection and calculation. A significant proportion of this time will be required to gather and check data on metals from Statistics Denmark.

In addition to updating the data basis, some man-days must be set aside for presentation, assessment and reporting of developments, which is assessed to require 5-10 man-days, depending on requirements for presentations.

6.2.3 Overall assessment of scope of update

The discussion of the amount of time required to prepare a status and current updates of realised savings is summarised in Table 6.1. It should be noted that in the annual updates, time for reporting has been included.

Table 6.1
Total time required for statement and annual calculations of indicators

Activity	Time required	
	Quantitative waste data	Life-cycle data
I) total impact, status, 1st time (Model A)	12-30 man-months [1)]	2 man-months
II) Realised savings and potentials 1st time (Model B) [3)]	3 -5 man-months [2)]	2 man-months
III) Annual statement, realised savings (Model B)	1 - 1½ man-month [2)]	½ man-month

1) The more applicable data is found in updated material flow statistics and mass-flow analyses, the less time is required for the update.
2) The first time, calculations will be presented, commented and assessed in a comprehensive report. In subsequent years the report will be updated and commented in roughly the same manner as the first time. Thus assessment and presentation are estimated to require less input.
3) Time required is stated under the assumption that statuses *should not be made* (calculation Model A).

7 Discussion

The purpose of the project is to assess the possibility of developing indicators for environmental impacts from management of all waste. The study has covered a determination of the purpose of indicators as well as an assessment of available calculation methods, relevant data material as well as time required to conduct the indicator calculation for the entire waste management field. Below, the considerations having emerged in the course of the project are summarised.

7.1 Purpose of indicator calculation

On the basis of current statements of waste management, the study finds that there may be a need to supplement the statement with a qualitative assessment of waste streams. The purpose may be partly a prioritisation of efforts in relation to different material fractions, and partly a prioritisation among the different treatment options.

In the project two proposals for calculation of indicators have been considered, referred to as Model A and Model B. From a calculation point of view they are relatively similar, but in terms of data they require somewhat different input.

If the purpose is to provide an outline of the relative contribution to resource and environmental impacts on the surroundings from the different waste fractions, Model A is more relevant. It gives the possibility, for example, to identify areas where the environmental impact from waste can be reduced by *reducing waste generation* or by promoting the use of alternative materials in product manufacture. This perspective is interesting, but calls for changes in manufacture of goods and consumption patterns, which are beyond the scope of this project.

If the purpose is to focus on environmental and resource benefits and potentials from an *optimisation of waste management* in the entire waste management field, Model B will be sufficient. If Model B is carried out for all waste fractions, it will be possible to identify the largest resource and environmental savings in waste management. It will also be possible to supplement with calculations focusing on which fractions hold the largest potential for further savings. Finally, it will be possible to limit the statement to some selected fractions for which there is a wish to assess resource and environmental benefits from the selection of different waste treatment options.

7.2 Assessment methods

The trial run, including the calculation and results from it, calls for a discussion of the degree to which the indicators calculated contribute with information that was not already available. Two interesting points should be mentioned.

One of the points is that focus is on life-cycle-based indicators. Thus, aspects have been included of materials having caused energy consumption, resource consumption and landfilling upon manufacture. For example, minerals extraction generates waste from mining. This means that the indicator for landfilling of waste in several cases can lead to surprising results.

At the same time, impacts from waste management are also included – for example credits for energy from incineration or recycling/landfilling of slag from incineration. The fact that such aspects have an impact on the assessment of waste treatment has been seen clearly in the trial run of the three materials.

The second point is that a statement using the three indicators results in a significantly different picture of waste fractions' relative impact compared to pure quantitative statements. In particular, the calculation shows that despite relatively small waste quantities, aluminium has a significant weight when using resource indicators. By contrast, resources such as sand, constituting the basis for glass, hardly have any weight at all. This may give reason to consider on which measures are most relevant for promotion within waste management.

In Chapter 5 the different indicators are assessed as well as the environmental and resource-related aspects they focus on in connection with the waste fractions tested. It seems that resource consumption and energy consumption supplement each other in an expedient way. Even if in some ways there is a certain degree of duplication, because energy is part of the indicator for both resources and primary energy, the two indicators express very different aspects of energy use. Whereas energy as a resource focuses on non-renewable resources, the indicator for primary energy expresses to a high extent environmental impacts due to, for example, greenhouse gases and acidifying substances. Thus, the energy factor is important as a supplement to the resource factor. The energy consumption indicator has the advantage compared to most environmental impacts that it is a rather certain parameter for which it is relatively easy to aggregate several forms of energy.

Due to the weighting of resources in the EDIP method the loss of a limited resource, such as copper, will weigh more than for example wood which is in principle regenerated if resources are not over-exploited. This dimension is an important aspect of the EDIP project that makes it possible to discuss resource problems in a far more qualified way than hitherto. For example, the principle has been applicable to assess whether recycling of slag is a matter of resource savings or rather a question of reducing landfill requirements. The calculation showed that in the overall perspective the reduction of landfill requirements is far more important than the resource savings from substitution of gravel.

7.2.1 Deficiencies in LCA data basis

There are several examples of LCA methods being deficient, for example concerning the data basis. For the resource parameter it is decisive that relevant information on the supply perspective is available for the different raw materials. One example from the project of lack of data is sulphur, where a statement of world resources taking extraction of sulphur from fuel into account is not available. If only resources of relatively readily available sulphur are taken into account, the resource factor, for example for paper, will be highly influenced by this single factor.

The landfill factor must still be considered as a temporary measurement until in connection with the further development of LCA methods, a clarification is available on how to state environmental impacts from landfilling. Particularly for organic material fractions such as paper, landfilling does not result in a permanent need for landfill capacity, but will result in the generation of, for example, greenhouse gases. At the same time the landfill factor in quantitative terms needs a weighting of environmental impacts from different waste fractions for landfilling.

In the choice of parameters, simplification has been made where environmental impacts for practical reasons have been disregarded. By merely reflecting resource consumption, energy and landfill requirements, the indicators may give a distorted picture and call for prioritisations in the waste management field that would be inexpedient from a broad environmental impact aspect. Therefore, indicators for some fractions where environmental contaminants are involved, such as heavy metals or persistent organic compounds, must be supplemented with other assessments than waste quantities. This is the case, for example, for assessments of all hazardous waste where the three indicator values cannot stand alone.

7.3 Assessment of data basis

The study of the existing data basis discussed in Chapter 6 showed that a mapping stating all waste streams (Model A) is only feasible, if concurrently a relatively extensive study of a number of material fractions is carried out concurrently, for example through an update of existing mass-flow analyses or material-flow statistics.

The other presentation model showing realised savings (Model B) with a less extensive effort can be used as an indicator calculated annually on the basis of existing waste statistics supplemented with other types of studies and statistics. It can show whether the objectives set up for recycling are met and add information on potentials for increased recycling of a material fraction.

7.4 Conclusions and recommendations

A focal point of the discussions under the project has been to identify which indicators can be calculated compared to what indicators should show. This has resulted in calculations being presented in two different ways, each with their strengths and weaknesses. Due to data uncertainties and deficiencies, indicators for both models must be regarded as a supporting tool in a decision-making process incorporating several factors. A current publication of indicator values to a wider audience will require presentation of a number of assumptions and reservations.

The indicator calculation cf. Model A can give a status for the resource and environmental impact of most waste fractions, but as described above it is relatively extensive. At the same time the results generated can primarily be used for a discussion of needs for reducing waste generation through intervention in the production and consumption stages, which is beyond the scope of this project.

Model B will be suitable for meeting the most essential purpose of indicator calculation: to identify the most significant resource and environmental potentials from further optimisation of waste management. At the same time, Model B can also document that efforts so far for environmental optimisation of waste management have actually generated results.

Model B can be carried out the first time with an input of 8 man-months and can be updated annually with an input of around 2 man-months (including provision and updating of LCA data).

It is important for the assessment of the amount of time required to know the audience to whom results are to be presented. In the presentation of the different results in the trial run, a balance has been sought between simplification and aggregation in order to satisfy the interested waste expert. Therefore a number of figures have been referred to the appendices. If results of an indicator calculation are to be presented to a wider audience it will probably be necessary to aggregate results for presentation further. Concurrently, a form of presentation of more detailed documentation should be identified. Some kind of electronic presentation through databases will be suitable, as it can give the user a tool to search for the information needed. Presentation of this type, however, is not part of the above-mentioned assessments of amount of time required.

8 Glossary

8.1 Life-cycle terms

LCA	Life-cycle assessment. Statement of all inputs and outputs from manufacture, use and disposal of a product, a product system, a service or a process.
EDIP	Environmental Development of Industrial Products. The first and largest Danish project on LCA method development – conducted by Institute for Product Development at the Danish Technical University.
EDIP PC tool	The Danish Environmental Protection Agency's computer programme for LCA statement cf. the EDIP method. Contains a number of process data from the EDIP project.
EDIP method	Consists of statement of input/output quantities for a product as well as the three assessment stages: Characterisation, normalisation, weighting. For each stage, a factor is associated with resource consumption and emissions.
Characterisation	Each *resource* is stated as the amount of raw material in the resource. In the characterisation *emissions* are divided into a number of categories according to environmental impact, such as global warming. An emission can contribute to several environmental impacts. All emissions with the same environmental impact are converted into a common unit, for example CO2 equivalents. 1 gram of methane gas, for example, is converted into having the same global warming effect as 25 g of CO2.
Normalisation	For each resource and for all emissions the characterised amount is converted into *person equivalents* (PE) by relating the amount to annual consumption or emission for one person. Renewable *resources* are related to consumption per person in the local area (DK), whereas consumption of non-renewable resources is related to consumption per person in the world. For *emissions* to the surroundings global warming and ozone-depleting effect are related to emissions per person in the world, whereas other parameters are related to emissions per person in Denmark.
Weighting	Normalised values as a last assessment stage can be weighted. For *resources* weighting is made against supply

perspective cf. statistics /36/. This means in practice that resource consumption is normalised in relation to total reserves in the world per person in the world instead of normalisation in relation to annual consumption per person in the world. The unit thereby becomes PR – person reserves. For *emissions* the normalised values are weighted with the politically decided reduction objectives in a certain year. Whereas there is reasonable consensus on the characterisation and normalisation stages, the weighting method is more debated, which is reflected in a number of methods developed under different LCA studies worldwide.

Allocation — Means distribution and is used for distribution of environmental impact upon co-production of several products and for distribution of environmental impact on virgin and recycled materials when the material is covered by one or more recycling trips.

Loss of utility value — Used in the EDIP for loss of quality upon recycling of a material. For example, paper fibres that are shortened every time paper is recycled. Loss of utility value is not identical to loss upon collection.

8.2 Indicator parameters

Resources — In this project a collective measurement for raw material consumption stated in PR (see weighting). Resources are used in the EDIP context as a synonym to raw materials.

Primary energy — Also called gross energy consumption. In this project primary energy consumption has been normalised to person equivalents in relation to Danish primary energy consumption per person in 1998. 1 kWh electricity (net) in calorimetric terms corresponds to 3.6 Mega joule. But in life-cycle statements 1 kWh electricity (net) corresponds to around 10 Mega joule (gross or primary energy), since a conversion and transmission loss takes place at the power plant. This is an important factor in all forms of energy conversion, but is particularly high in electricity generation.

Landfilling — In this project waste quantities for landfilling stated in person equivalents in relation to Danish quantities of waste for landfilling per person in 1998.

8.3 Waste terms

Waste management — All forms of waste handling and treatment.

Energy recovery — Incineration of waste with recovery of energy.

Recycling — Material recovery where a material is reprocessed for use in new products that are not necessarily the same as the original products. Recycling does not cover energy recovery.

Reuse — Upon reuse, a product is reused for its original purpose. For example reuse of beer bottles.

ISAG — Danish Information System for Waste and Recycling. Came into use in Denmark in 1993. Its purpose is registration of sources and waste treatment option for some general waste fractions. Waste treatment enterprises report to the system.

EWC — European Waste Catalogue. A list of waste drawn up under Council Directive 75/442/EEC on Waste. The list is not an exhaustive list of waste. Waste included in the list and marked in bold type is hazardous waste when criteria for hazardousness are complied with.

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Appendix A

Screening of waste

1 Waste fractions and environment

In this appendix, a screening will be made of present options for each waste fraction as to management and treatment as well as the most significant consequences for the environment and resource consumption associated with these options. A summary is in Chapter 3. For each waste fraction, the subsection is divided into:

- Treatment options
- Resources and environment
- Data basis

The purpose of this screening is to identify environmental impacts and resource consumption considered to be significantly different among alternative management options. In the identification, a number of assumptions are made that will either be confirmed or discounted in more in-depth analyses, if relevant.

For all waste fractions there will be some general aspects, and these are discussed below. Furthermore, the statistical basis for waste is described briefly. In Appendix B this is supplemented with a more detailed assessment of providing relevant data for an indicator calculation.

In relation to *recycling* products and materials a distinction will be made between three levels of recycling:

Reuse, using the product once more, often after cleaning (for example, reuse of beer bottles).

Direct recycling, fully exploiting the qualities of the secondary material in new products (for example, remelting glass in the manufacture of new bottles).

Indirect recycling, using materials once more, but only partially exploiting the qualities of the material (for example, recycling glass in the form of slag from waste incineration). Indirect recycling is similar to the term "downcycling". Indirect recycling, exploiting the energy contents of the material will be referred to as energy recovery.

Waste minimisation, reducing the waste quantities will – all other things being equal – reduce environmental impacts from waste treatment. Environmental impacts associated with previous life-cycle stages will only be included in the present analysis to the extent that they have an impact on the choices made in connection with waste treatment and recycling, which are the focus of the project.

All processes will to some extent require *energy,* and in a life-cycle perspective, therefore, a number of energy-related environmental impacts and resource consumption will be associated with all choices in the waste management field. For many processes, energy consumption constitutes a significant part of the contribution, particularly to global warming and acidification. Energy consumption also contributes to resource consumption of both renewable and non-renewable energy resources.

Energy consumption also has a significant impact in connection with, for example, waste incineration, recovering energy contents in waste for heat and, to a lesser extent, power generation. In a life-cycle examination of waste treatment it will be necessary to include consequences on the environment and resource consumption associated with the fact that waste substitutes other fuel. Other treatment options, for example gasification of waste, also exploit energy contents in waste, but further preserve material resources. Under the present project, such perspectives will be incorporated when relevant.

To avoid repeating the above statements on consequences from energy consumption for all relevant waste categories, the following states when there are significant differences in energy consumption associated with the different choices, without going into detail about derived environmental impacts and resource consumption. By treating energy as an individual item, other resource and environmental issues associated with specific waste treatment options will appear specifically from the discussion.

1.1.1 Data basis

The Danish Environmental Protection Agency collects data on waste and recycling. Since 1993, overall waste statistics have been published annually, and the most significant data basis derives from statutory reports to the Agency from all waste treatment plants – the so-called ISAG system (Information System for Waste and Recycling).

ISAG reports do not cover total waste generation in Denmark. For example, coal-fired power plants are exempt from reporting to the ISAG, as figures are collected directly from the power companies Elsam and Elkraft. Correspondingly, figures for sludge from municipal wastewater treatment plants for spreading on agricultural land are found in regional reports to the Danish Environmental Protection Agency on sludge generation and in data on waste from sugar works. Certain figures on imports and exports of waste are collected from the Association of Danish Recycling Industries and the Danish Environmental Protection Agency's registrations of imports and exports of waste under the EU Regulation on shipments of waste.

For a number of areas, more detailed statistical studies are prepared for a number of waste types. Waste Centre Denmark prepares a number of individual and continuous studies of, for example, household waste, packaging waste and compost.

For chemical waste, significant changes were made in 1997 to reporting to the ISAG system /35/, due to the fact that the EU requires more specification of contents in waste. Previously, such data was found through information from the hazardous waste treatment plant, Kommunekemi, that used to be the only treatment plant for hazardous waste in Denmark.

For recycling, the ISAG system has a weak point, as it only deals with separated fractions. This means that the fraction of paper and cardboard for example, only covers amounts separated for recycling. Thus, the ISAG does not give a picture of actual potential, as a large proportion of paper is found in the mixed category of ”various suitable for incineration”.

To get an outline of potentials for recyclable materials and rates of recycling for the different fractions, it is necessary to compare supply statistics, for example, for paper consumption, with quantities collected. This has been done for a number of areas, and potentials for recycling have to a large extent been summed up in the Danish Government's Waste Management Plan /37/ and in detailed annual statements from Waste Centre Denmark. In a number of areas – particularly for metals – detailed mass-flow analyses have been made, giving a good status of consumption and waste treatment.

1.1.2 Division into categories

In this screening of present and possible treatment of the different waste fractions, the starting point is the STANDAT list of codes, level 1 /20/. The division has been adapted regularly, most recently with the latest Statutory Order on Waste /35/. For example, the division of paper, plastics and hazardous waste, such as sludge, incineration residues and all waste from health-care risk waste to waste oils has been specified in more detail. One of the significant elements of the latest Statutory Order on Waste is harmonisation with the future EU regulation on waste statistics.

In addition to ISAG data, groups have been added with treatment residues and sewage sludge. Some fractions are discussed jointly in this report. For each fraction, a short description of what it covers is given.

Waste fractions discussed in the screening
- Paper and cardboard
- Bottles and glass
- Plastics (divided into PVC and other plastics)
- Food waste/other organic
- Branches, leaves, grass etc. (+Bark and wood chips and compost removed from plants)
- Iron and metals
- Automobile rubber
- Concrete, tiles (two fractions)
- Asphalt
- Other construction/demolition
- Wood
- Soil and stone
- Other recyclable
- Health-care risk waste
- Various suitable for incineration
- Various unsuitable for incineration
- Sludge
- Sand and screenings
- Slag, fly-ash and flue-gas cleaning products (three fractions)

- Dust-emitting asbestos
- Oil and chemical waste
- Electrical equipment (two fractions)

1.2 Paper and cardboard

1.2.1 Treatment options

Table 1.1: Treatment options for paper and cardboard

Treatment option	Comments
Reuse	Reuse of paper and cardboard only takes place to an insignificant extent. In principle, however, it is possible to reuse cardboard boxes.
Direct recycling	Paper and cardboard is recycled for the production of corrugated cardboard, packaging paper, cycle paper, egg boxes etc.
Indirect recycling	Paper that is not collected separately will primarily be led to incineration. In incineration plants with energy recovery paper is used as a fuel for the generation of heat/power
Incineration without energy recovery	In incineration plants without energy recovery paper in principle will be destroyed, generating minor ash residues.
Landfilling	May take place to the extent that paper and cardboard is mixed with waste unsuitable for incineration, such as construction and demolition waste

1.2.2 Environment and resources

Environmental issues associated with waste treatment and recycling of paper and cardboard have been analysed in detail in a number of reports on environmental economics for paper and cardboard cycles /12/.

The basic question is whether paper should be recycled directly, avoiding some of the environmental impacts from production of new paper, but leading to other environmental impacts from collection and reprocessing of paper bulk, or whether it should be incinerated, ensuring recovery of the calorific value of paper.

In addition to wood, a number of chemicals are used in paper production for bleaching, boiling, and deinking (of recycled paper bulk), just as paper is mixed with glue and fillers such as lime and kaolin. Recycling paper requires less use of chemicals than production of virgin paper.

Table 1.2: Significant environmental issues for incineration compared to recycling paper

	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-fillin g *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
recovery/ incinera-	xx	x		X		x	x	xx

tion								

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Overall, energy-derived environmental impacts are in focus in the two most important treatment options for waste paper. Particularly, issues associated with substituted energy resources may be significant. Resource consumption for the production of paper primarily covers wood; a renewable resource, so this is of minor importance.

Eutrophication of the aquatic environment may be significant, if wastewater from paper production is not treated. Wastewater treatment in paper production is generally very good at Nordic paper manufacturers.

For emissions of toxic substances to the environment a significant reduction has taken place in recent years, as bleaching with chlorine has been substituted by processes with less impact on the environment. However, there is still a risk of emission of toxic substances, for example from deinking of paper for recycling.

Working environment impacts from separation of paper for recycling may be significant, but the data basis for such an assessment is insufficient.

1.2.3 Data basis

Table 1.3: Data sources for waste paper

ISAG system	Annual statistics	Statuses etc.
Quantities of recycled paper make up the fraction ”paper and cardboard for recycling”. Other paper used is included in the fraction ”various burnable”.	Annual statements of paper consumption (on the basis of supply statistics) and recycling of paper (waste paper statistics from Waste Centre Denmark). Current statement of consumption of paper and cardboard packaging (Waste Centre Denmark)	Statements of potential for paper recycling for all municipalities (The Danish Environmental Protection Agency and Econet). Status of paper in domestic waste /5/.

It appears from the above that it will be possible to obtain an annual, updated statement of consumption, incineration and rates of recycling for paper. For 1998 this rate reached 50%. In addition, it will be possible to some extent to obtain a continuous statement of application of paper.

1.3 Bottles and glass

Bottles and glass covers all products of glass, except from glass in electrical and electronic equipment. The reason for this distinction is that special problems occur in the treatment of technical glass.

1.3.1 Treatment options

For bottles and glass it is relevant to distinguish between the following treatment options:

Table 1.4: Treatment options for bottles and glass

Treatment option	Comments
Reuse	Bottles and other glass packaging that can be washed and refilled. Reuse can take place in deposit-return schemes, or in separation of mixed bottles and glass collected. Reuse in households is not included, as this is merely considered as a longer useful life
Direct recycling	Relevant for all types of glass. In remelting, glass can be used for the manufacture of bottles and glass packaging or glass wool.
Indirect recycling	Glass for incineration will end up in slag, and as such it can be used for construction purposes
Landfilling	Covers glass landfilled directly (including collected and rejected glass) and glass in incineration slag that is not used for construction purposes

1.3.2 Environment and resources

The manufacture of glass from raw materials or remelting of cullet into new glass requires energy. Also direct reuse of bottles for example requires energy for transportation and washing.

Upon reuse of bottles, resources can be saved for manufacture of virgin glass. The most important raw materials for glass manufacture are soda, sand and lime, but in addition a number of auxiliary substances are used. Substitution of raw materials will be ensured through both reuse and recycling of glass.

Table 1.5: Significant environmental issues for incineration compared to recycling of glass and bottles

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophicatio n	Local: ozone (smog)	Tox eco/ hum		
Glass R/L	x	x		x		x	x	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Upon landfilling or recycling in the form of slag from waste incineration, glass must be considered to substitute raw materials such as gravel and sand, having less resource value than glass for remelting. Recycling of slag from waste incineration for construction purposes requires that glass is incinerated together with other wastes that do not give rise to environmental contaminants in slag, such as heavy metals.

Energy-derived environmental impacts are in focus in the differences between reuse and recycling of cullet and in landfilling, or through slag from incineration plants. However, differences are not very significant in the choice between reuse and remelting.

Resource consumption for manufacture of virgin glass primarily covers resources that are found in Denmark in large quantities. For glass contained in slag used for construction purposes, the resource sand will be recovered, as slag substitutes other use of sand. Landfilling, however, will lead to loss of resources.

For reuse of bottles, the bottles must be washed, and this may cause eutrophication from wastewater discharges. In Denmark, however, this problem is mitigated through wastewater treatment.

To a minor extent, toxic substances may be used in connection with washing bottles. In the manufacture of virgin glass the use of mould oil and other auxiliary substances may cause a (minor) impact from toxic substances.

Glass for landfilling – either directly or in the form of slag from waste incineration – will increase the total volume of waste and thus landfill requirements. Landfilled glass without heavy metal contents is not assumed to have long-term toxic impacts, but when mixed with other waste fractions it will contribute to total volumes.

1.3.3 Data basis

Table 1.6: Data sources for bottles and glass

ISAG system	Annual statistics	Statuses etc.
The ISAG only states quantities of bottles and glass for recycling. Other glass is included particularly in the fractions ”non burnable” and ”construction and demolition waste”.	Annual statements of glass packaging (on the basis of supply statistics) and reuse and recycling of bottles and cullet: ”Glass, bottles and cullet” from Waste Centre Denmark /18/. Glass packaging is also included in current packaging statistics /27/. Glass for buildings is not stated.	Waste glass from households is included in ”Domestic waste from private households” /5/.

1.4 Plastics

Plastics constitute a very complex group, since many types of plastic, in addition to the raw polymer contain a large number of additives: stabilisers, flame retardants, softeners, pigments etc. Thus, there are a number of important factors that will be different from one type of plastic to another, and this makes it difficult to discuss plastics jointly. PVC differs from the other types, as it causes special problems.

1.4.1 Treatment options

For plastics it is relevant to distinguish between the following treatment options:

Table 1.7: Treatment options for plastics

Treatment option	Comments
Reuse	Direct reuse of plastic products takes place in the form of reuse of plastic packaging.
Direct recycling	Direct recycling, with granulation of plastics and application for the same purpose as the primary plastic material is currently carried out for certain types of transport packaging and production waste.
Indirect recycling	In indirect recycling, plastic from cables, for example, is used for production of traffic equipment.
Energy recovery	Plastics that are not collected separately will primarily be incinerated. In incineration plants with energy recovery plastics are recovered as a fuel for the generation of heat/power
Landfilling	Plastics in composite products to some extent will end up in landfills, for example in the form of shredder waste.

1.4.2 Resource and environment associated with plastics (except from PVC)

Environmental profiles for different plastic types, for example PET /7/, have been drawn up by the Association of Plastics Manufacturers in Europe - APME. In the manufacture of plastics, in addition to energy-related environmental impacts, there may be a significant contribution to photochemical ozone formation (VOC emission) and waste problems associated with, for example, sulphur and heavy metals that are removed from crude oil in the manufacture of plastics raw materials. In both reuse and recycling of plastics environmental and resource savings are possible.

In indirect recycling of plastics, expedient exploitation of additives contained in waste plastic types often does not happen. For heavy metals and resource consumption for the production of additives it will therefore be relevant to set indirect recycling equal to landfilling.

Special problems are associated with recycling plastic types containing heavy metals or other undesired substances, as upon recycling substances are kept in circulation and potentially spread to the surroundings.

Upon incineration, recovery of the energy contained in plastics is ensured to some extent, but for some plastic types energy consumption for the manufacture of plastics may be significantly larger than the energy recovered. Apart from PVC, only a modest number of plastics contain halogens in the polymer structure, but halogenated additives are widespread, particularly in the form of chlorinated and brominated flame retardants. Upon incineration of plastics, emissions of problematic substances may thus occur, particularly dioxin, just as in connection with flue-gas cleaning, considerable amounts of flue-gas cleaning products will be generated that are added to neutralise the acids formed.

Both upon incineration and landfilling of plastics with heavy metal containing pigments (lead, cadmium, copper, zinc) there may be long-term toxic effects.

Upon recycling there is a considerable loss of plastics: one quarter of plastic packaging collected is treated as waste in connection with recycling /28/. This indicates that in a calculation it will be also necessary to include the destiny of materials led to recycling.

1.4.3 Environment and resources for PVC

Chlorine contents in PVC cause a number of specific environmental impacts both in connection with the manufacture of chlorine and in waste treatment. Upon incineration, dioxins and hydrochloric acid are formed, and upon flue-gas cleaning larger amounts of residues are generated than the amount of PVC incinerated.

In addition, hard PVC often contains stabilisers such as lead, cadmium and other heavy metals that cause problems in waste treatment.

Due to these issues PVC will be stated apart at first, as it is expected that environmental benefits from direct recycling are more pronounced for PVC than for other plastic types. This assumption, however, must be verified.

Table 1.8: Significant environmental issues for incineration compared to recycling of plastics.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Plastics R/I	x	x		x	x	xx	x	x

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

In an overall assessment of environment and resource-related differences between recycling and incineration of plastics, several aspects are of importance. Resource and energy consumption for manufacture of plastics is important, as upon recycling into new plastic products energy resources may be saved, as plastics are manufactured from oil. Upon incineration of plastics, energy recovery will lead to substitution of other energy. Overall, from an energy and resource point of view there are probably no significant differences between recycling and incineration of plastics.

Emissions and waste associated with treatment of plastics, however, may be significant – particularly concerning PVC. As regards emissions, especially the content of acidifying substances (HCL) causes problems – which may be ”converted” into a waste problem concerning landfilling of flue-gas cleaning products. Most plastic types may contain heavy metal residues from dyes and additives. PVC furthermore may cause formation of dioxins, so toxic effects from plastics incineration is a very significant issue.

In addition to landfilling of flue-gas cleaning products, plastics that are not clean or cannot be sorted are also landfilled upon recycling. The rate may be significant.

Finally it should also be mentioned that upon separation of plastics for recycling, there may be problems associated with the working environment, an issue that has not been studied sufficiently.

1.4.4 Data basis

Table 1.9: Data sources for plastics

ISAG system	Annual statistics	Statuses etc.
Quantities of plastics for recycling make up the entire fraction. Other plastics used are contained in particular in the fraction ”various burnable”	Annual statements of plastic packaging /28/* Other plastic consumption not stated regularly	Studies on PVC consumption in general as well as on PVC for use in the building sector, see also Waste Centre Denmark /3/. Status of plastic amounts in domestic waste /5/

*) In the Plastic packaging statistics figures are stated for plastic packaging collection, broken down by the plastic types: LDPE, HDPE, EPS, PP, PET, PS and "Other plastics" /28/. The rate of collection, and thus amounts of plastic packaging that are not collected for recycling are calculated in the statements by comparing collected quantities with supply of plastic packaging.

At European level, plastic packaging accounts for around 57% of total amounts of plastic waste incl. PVC /28/. For other waste plastic types no continuous statistics are made, but this plastic is almost exclusively incinerated or landfilled today.

No regular statement of incineration and landfilling of PVC is made, but collection rates for PVC in building and construction waste have been estimated in several PVC studies. However, the most recent statement covers 1996 /3/.

1.5 Food waste and other organic waste

1.5.1 Treatment options

For food waste and other organic waste that is source separated, it is relevant to distinguish between the following treatment options:

Table 1.10: Treatment options for food waste etc.

Treatment option	Comments
Reuse	
Direct recycling	Animal fodder is only manufactured from waste from catering kitchens
Indirect recycling, energy	Anaerobic gasification for biogas generation gives an energy benefit compared to incineration.
Indirect recycling	Composting either in central plants or in the individual households preserves nutrients.
Incineration without energy	Incineration may cause certain environmental problems.

recovery	
Landfilling	Decomposed relatively fast upon generation of methane gases released to the surroundings. In addition, leachate is formed.

1.5.2 Environment and resources

Organic waste collected from professional sources primarily consists of food waste that can be used directly as animal fodder. This consumes energy for reprocessing, but far less than what is used for manufacture of fodder from virgin raw materials.

Household waste to a large extent consists of organic material. However, today only a limited amount of household waste is source-separated, but this area has been given high priority in Waste 21. The largest part is used for composting, but as a trial a minor part is used in anaerobic gasification plants. Finally, a large part of organic household waste may be home composted. This treatment does not recover energy contents in waste, but it saves energy for waste transportation.

From an energy and resource point of view, gasification ensures the best recovery, as energy is recovered and nutrients in materials are recovered as a fertiliser without any significant contents of heavy metals and similar. Methane gas released from the gasification process and from incomplete burning of gas may contribute significantly to global warming.

Table 1.11: Significant environmental issues for incineration compared to recycling of food waste

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Food waste R/I	x	x	xx			x		?

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Incineration of food waste gives a poor energy yield due to the high contents of water that may lead to poor incineration. Furthermore, contents of chlorine, for example in table salt, may cause formation of environmentally harmful substances in the incineration process.

Overall, there seems to be energy and resource-related advantages from recycling food waste into animal fodder, as the manufacture of new fodder requires energy, and incineration of food waste contained in household waste does not give large energy yields. The possibility of treating food waste together with other organic waste in anaerobic gasification may also provide a good exploitation, as both energy and nutrient resources are recovered. In return, gasification may contribute significantly to global warming.

In the incineration of food waste the contents of table salt may increase the risk of very toxic dioxin formation.

Finally, there may be important working environment issues associated with the management of food waste that have not been studied.

1.5.3 Data basis

Table 1.12: Data sources for food waste etc.

ISAG system	Annual statistics	Statuses etc.
Quantities of recycled food waste from commerce are included in the fraction ”food waste/other organic waste” together with source-separated domestic waste. The rest is mainly included in the fraction ”various burnable” that also covers mixed domestic waste.	Annual statements of compostable quantities from households and industry in compost statistics from Waste Centre Denmark /4/.	Status of domestic waste /5/, where quantities of food waste found in separation of household waste appear.

The ISAG system contains data on amounts collected for animal fodder from enterprises and institutions as well as source-separated domestic waste. Potentials of organic waste in household waste are considerable, but no continuously updated statements are available. The most recent statement dates from 1994 /5/, where food waste is stated to constitute 36% of domestic waste. Waste Centre Denmark regularly prepares compost statistics that estimate amounts of home-composted household waste /4/.

1.6 Branches, leaves, grass etc. (and compost)

1.6.1 Treatment options

For treatment of collected branches, leaves, grass etc. a distinction is made between the following treatment options:

Table 1.13: Treatment options for branches and leaves etc..

Treatment option	Comments
Reuse	
Direct recycling	Crushing to chips, locally or at waste treatment plant
Indirect recycling, energy	Incineration with energy recovery
Indirect recycling	Composting, either in central plants or in the individual household preserves nutrients.
Incineration without energy recovery	Incineration reduces amounts and is selected in some cases, for example in connection with cleaning-up etc.
Landfilling	Decomposes relatively fast upon formation of methane gases that are released to the surroundings.

1.6.2 Environment and resources

For the environment and resources there are significant differences among recovery for chips or compost, and incineration with or without energy recovery. In an energy statement, the need for transportation associated with the different treatment options should also be included.

Upon incineration in the open land energy and resources are lost. As open burning does not give optimum incineration, pollution with, for example, PAH may be significant.

Upon storage and composting, materials to some extent will decompose, forming methane gases that contribute to global warming.

Table 1.14: Significant environmental issues upon incineration compared to recycling of garden waste

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophicatio n	Local: ozone (smog)	Tox eco/ hum		
Garden waste R/I	x		xx					

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

The focal point of the assessment will be energy, as the resource in question is renewable. But in a life-cycle perspective energy considerations may be rather involved. For example, recovery upon incineration may reduce consumption of other non-renewable resources, whereas utilisation as compost or chips may reduce consumption of fertilizer the production of which also requires energy.

All organic material may contribute to global warming if it is stored in a way that allows a gasification process to start – or for example in home composting.

1.6.3 Data basis

Table 1.15: Data sources for garden waste

ISAG system	Annual statistics	Statuses etc.
The group garden waste consists of collected material from households. Compost quantities produced are also registered in the ISAG. Bark and wood chips, for example from parks, is not registered if it is treated directly on site.	Annual statements of compost and estimated potentials from households, including garden waste, are stated/estimated in the compost statistics from Waste Centre Denmark.	

The ISAG system contains data on collected amounts of materials as well as statistics of used (removed) amounts of compost and chips. In 1997 more than 90% of composted waste was used in the same year, the remainder being stored. Over half was used in private gardens.

Bark and wood chips is not registered in the ISAG if it is treated and used directly on the site of generation, for example in parks and churchyards etc.

1.7 Iron and metals

1.7.1 Treatment options

For iron and (other) metals it is relevant to distinguish between the following treatment options:

Table 1.16: Treatment options for iron and metals

Treatment option	Comments
Reuse	Reuse of metal products takes place to a certain extent, for example with small scrap dealers, but this metal is not assumed to be registered as waste.
Direct recycling	Direct recycling is the most widespread form of recycling metals. However, a certain utility loss may take place upon recycling.
Indirect recycling	Metals may be included in slag from incineration plants used for construction purposes. All heavy metals not desirable in slag
Landfilling	Landfilling of some metal is assumed to take place, for example together with construction and demolition waste.

1.7.2 Environment and resources

Upon recycling, in addition to resource and energy savings, a reduction in environmental impacts associated with extraction of metals is achieved. Significant environmental impacts include spreading heavy metals upon raw material extraction, acidification, greenhouse effect, occupation and long-term deterioration of land. In extraction, large waste quantities are often generated. For example, around 300 tonnes of waste are generated for each tonne of copper. For metals it is thus very important to include these early phases of the life-cycle.

All iron and metals collected are led to recycling. However, there will be a certain loss in connection with recycling. Metals are often used in alloys, and in recycling a loss of utility value may occur, as the qualities added by alloy elements to the alloy are not exploited in the secondary material. In addition, alloy elements may instead become polluting elements in the secondary material, for example, in the remelting of steel or aluminium. These utility value losses must be considered as resource losses of alloy elements.

Table 1.17: Significant environmental issues for incineration compared to recycling waste metal

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Metal R/L	xx	xx		x		xx	x	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

For metals incinerated or landfilled it may be significant to distinguish between heavy metals (lead, mercury, cadmium etc.) and other metals (iron, aluminium, magnesium).

In general, environmental impacts associated with resource and energy will be in focus for all metals, but in connection with raw material extraction and processing of raw materials there will be a large number of environmental impacts that are specific for the different metals. For example, carcinogens (PAH) and acidifying substances are released in connection with melting aluminium.

For heavy metals, in addition to a significant resource dimension, there is also an important problem associated with long-term toxic effects of heavy metals led to landfilling or included in slag used for construction purposes. Some of the heavy metals may also end up in filter dust, for example in connection with incineration of metal parts. This filter dust must be landfilled.

Seen from a life-cycle perspective, landfilling metals instead of recycling them will create a landfill requirement not only in connection with waste treatment but also to a high extent in connection with extraction of virgin materials, since mining often generates large waste quantities.

Regarding working environment, no overall statements have been made of advantages and disadvantages from the manufacture of virgin metals compared to recycling. However, some data is available on the manufacture of virgin metals, where mining, for example, may cause many accidents /19/.

1.7.3 Data basis

Table 1.18: Data sources for metals

ISAG system	Annual statistics	Statuses etc.
The quantity of recycled metal constitutes the group ”iron and metals for recycling”. However, the group is not specified according to metal types. The rest of metals used are mainly included in ”various unburnable” or ”other construction and demolition waste”.	Annual statistics of iron and metal waste are not prepared. In connection with waste statistics, the Danish Environmental Protection Agency gathers information on net amounts exported from the recycling industry and large scrap dealers.	Scrapped vehicles constitute a considerable part of waste iron and metal, and quite accurate statements are available on number of vehicles. Metal in household waste is included in Domestic waste from private households /5/.

Current waste statistics state total amounts of iron and metal scrap collected for recycling under iron and metal scrap. There is no information on individual metals, and the rate of collection has not been calculated. Waste Statistics 1997 state that the rate of recycling for iron and metal scrap exceeds 90%. The high rate of collection is due to the fact the rate of collection for iron and steel is very high, and iron and steel make up by far the major proportion of total amounts of metal. The rate of collection for most other metals, according to mass-flow analyses, is in general below 90%.

A precondition for detailed calculations of resource and environmental consequences of waste treatment of iron and metals is that specific information is available on management of the different metals, or at least the most important metals. Preliminary calculations can be based on mass-flow analyses that have been prepared for most metals.

Overall, due to the available statistical basis it is difficult to make a detailed statement for iron and metals.

1.8 Automobile rubber

1.8.1 Treatment options

For treatment of automobile rubber (tyres) a distinction is made between the following treatment options:

Tabel 1.19: Treatment options for automobile rubber

Treatment option	Comments
Reuse	Retreading
Direct recycling	Not possible
Indirect recycling, energy	Granulation and separation of metal parts. Incineration with energy recovery.
Indirect recycling	Granulation for paving material
Landfilling	Decomposes very slowly – steel and nickel resources are lost upon landfilling.

1.8.2 Environment and resources

Automobile rubber is manufactured primarily from artificial rubber with relatively high energy consumption for manufacture of the rubber material. Waste tyres are primarily reprocessed at one enterprise in Denmark. Tyres of good quality may be retreaded, and the rest granulated. Upon granulation metal parts of stainless steel, containing nickel for example, are separated.

Upon incineration of granulated artificial rubber only around 20-25% of energy from original production is recovered.

Upon retreading energy is saved compared to the production of new tyres.

Recycling of rubber as a paving material often substitutes other materials whose production requires far less energy. However, it also has some special properties that are requested for different purposes.

Table 1.20: Significant environmental issues for incineration compared to recycling of tyres

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophiation	Local: ozone (smog)	Tox eco/ hum		
Tyres R/I	xx	xx					x	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

The focal point of an assessment of environmental differences between reuse, recycling and incineration of tyres is energy and resource issues, as the production of new tyres requires energy and raw materials in the form of oil and nickel for stainless steel.

Upon incineration of tyres without prior granulation or upon landfilling, resources contained in stainless steel are lost.

1.8.3 Data basis

Table 1.21: Data sources for tyres etc.

ISAG system	Annual statistics	Statuses etc.
Collected automobile rubber is registered in the ISAG. Since the collection scheme covers all types of tyre since 1999, statistics are assumed to cover the major part of end-of-life tyres. Waste 21 states a recycling or incineration rate of more than 80% by 2004.	Annual statements of tyre consumption are found in the supply statistics. The Danish Tyre Trade Environmental Foundation registers collected amounts and treatment option /37/.	

The ISAG system contains information on automobile rubber. It can be supplemented with the Danish Tyre Trade Environmental Foundation’s statistics on the take-back scheme and statistics on retreading and granulation for rubber powder /40/. Large tyres (trucks and tractors etc.) have only been covered by the rules since 1999, and therefore they only appear in statistics since that year.

1.9 Concrete and tiles

1.9.1 Treatment options

For concrete and tiles the following treatment options are available:

Table 1.22: Treatment options for concrete and tiles

Treatment option	Comments
Reuse	Only relevant for tiles and, in some cases, concrete slabs
Direct recycling	
Indirect recycling	Crushing for backfilling material and aggregate
Landfilling	

1.9.2 Environment and resources

Tiles and bricks can be reused to some extent after cleaning and separation, if demolition is conducted carefully. The process is labour-intensive, but from an energy and resource point of view it is a good solution, as energy for production of new bricks is saved.

Indirect recycling through crushing recycles resources as a substitution for gravel etc. Upon use as aggregate for new concrete, the hardening properties of concrete are not exploited, and this use thus substitutes resources such as gravel and pebbles.

Resources used for reinforcement in concrete may be recycled upon crushing, but reinforced concrete parts are probably often used as harbour filling material etc., thus losing the resources contained in reinforcement iron.

Table 1.23: Significant environmental issues for incineration compared to recycling of concrete and tiles.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification / eutrophication	Local: ozone (smog)	Tox eco/ hum		
Concrete etc. R/L	x						x	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Energy consumption for crushing and transportation must be seen in comparison to excavation and transportation of new backfilling material, and it is estimated to be of a similar order. Upon reuse of tiles, which only takes place to a very limited extent, a slightly larger energy benefit is achieved.

Good source separation of construction and demolition waste is important to avoid contamination with toxic substances, for example in pressure-impregnated wood, PVC and electrical equipment. Such separation is already practised extensively, and focus on environmentally correct design will contribute to ensuring that this will also be possible in the future.

From a landscape point of view, recycling through crushing is of advantage, partly as it saves excavation of virgin materials, and partly as it reduces landfill requirements.

1.9.3 Data basis

Table 1.24: Data sources for concrete and tiles

ISAG system	Annual statistics	Statuses etc.
Amounts of concrete and tiles for recycling are covered by two different categories in the ISAG. A minor part is included in the fraction ”various construction and demolition waste” that is landfilled.	Annual statements of construction and demolition waste are prepared by Waste Centre Denmark /32/	

Amounts of recycled materials appear from the ISAG system. Waste Centre Denmark prepares special statistics on construction and demolition waste /32/. These statistics indicate annual amounts generated, giving the basis for calculating the rate of recycling for construction and demolition waste. In 1997 more than 91% was used for backfilling.

1.10 Asphalt

1.10.1 Treatment options

For asphalt the following treatment options exist:

Table 1.25: Treatment options for asphalt

Treatment option	Comments
Reuse	
Direct recycling	After crushing and mixing with virgin bitumen
Indirect recycling	Crushing for backfilling and aggregate
Landfilling	

1.10.2 Environment and resources

Asphalt is recovered to a large extent; either after demolition of paving, or directly in connection with ”milling off” paving, where crushing, heating and mixing with additional bitumen takes place. This is done either in stationary treatment plants or in mobile plants. Even if energy is required for heating and transportation, environmental and resource-related advantages compared to manufacture of new asphalt are evident, and the method is used extensively. Only asphalt mixed with other materials – such as concrete – is landfilled or crushed for backfilling.

Table 1.26:
Significant environmental issues for landfilling compared to recycling of asphalt

Fraction Typical treatment	Energy (incl. contribution from subst.)	Resources *	Environmental impacts *				Landfilling *	Working environment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		

Asphalt R/L	x	x				?	xx	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Upon recycling waste, energy and resources are saved, but primarily landfill requirements are saved for waste asphalt. The typical treatment options for waste asphalt do not seem to imply significant differences in pollution with toxic substances.

1.10.3 Data basis

Table 1.27: Data sources for asphalt

ISAG system	Annual statistics	Statuses etc.
Quantities of recycled asphalt at stationary plants are included in the ISAG. Asphalt processed on site without transportation is not registered in the ISAG.	Construction and demolition waste statistics /32/	

Quantities treated at stationary plants are registered in the ISAG system. Upon direct reuse of asphalt for new paving on site, quantities treated must not be reported as waste to the ISAG. Waste Centre Denmark has prepared a very detailed analysis of management of waste asphalt. From this it appears that almost all waste asphalt is recycled /32/.

1.11 Other construction and demolition waste

This group consists of mixed construction and demolition waste such as wood, insulation material, glass, metals, cardboard, plastics and problem wastes (for example electrical installations), and clean soil.

1.11.1 Treatment options

For mixed construction and demolition waste the following treatment options may be relevant:

Table 1.28: Treatment options for other construction and demolition waste

Treatment option	Comments
Reuse	Clean soil can be reused for backfilling.
Direct recycling	Upon source separation, recycling of a number of materials is possible in principle.
Indirect recycling	Incineration of wood, cardboard and plastic fraction.
Landfilling	Only possibility, if materials are not source separated

1.11.2 Environment and resources

To the extent that materials are not separated and recycled, a 100% resource loss will occur from landfilling.

In so-called selective demolition materials are separated during demolition. This allows for a very high rate of recycling (more than 90%). If the structure contains asbestos, working environment precautions must be taken upon demolition.

Building materials may furthermore contain environmentally harmful substances, for example in pressure-impregnated wood or electrical components. This concerns in particular various heavy metals. Apart from materials of wood or paper, other materials do not decompose in a short-term perspective, and waste will require space for landfilling.

Table 1.29: Significant environmental differences between landfilling, incineration and recycling of construction and demolition waste

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
C&D R/I/L	x	x				xx	xx	x

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Upon separation of construction and demolition waste a reduction in landfill requirements is achieved, and this also allows for reductions in long-term toxic effects from landfilling the environmentally most harmful part of waste.

There are also energy and resource-related advantages from better separation of construction and demolition waste, even if they are not in focus in the different treatment options for this fraction.

1.11.3 Data basis

Table 1.30: Data sources for other construction and demolition waste

ISAG system	Annual statistics	Statuses etc.
”Other construction and demolition waste” consists of materials collected for reprocessing.	Annual statements of construction and demolition waste /32/	

The group is covered by the ISAG system, and Waste Centre Denmark has carried out detailed studies of construction and demolition waste. However, the composition of the mixed ISAG fraction ”other construction and demolition waste” has not been studied. Waste 21 establishes the objective that a larger proportion of construction and demolition waste should be source-separated. In particular environmentally harmful material fractions such as impregnated wood and electrical equipment should be separated.

1.12 Wood

1.12.1 Treatment options

This fraction consists of wood collected from industry and commerce, and building and construction activities. Wood used for packaging is also covered. For wood the following treatment options are possible:

Table 1.31: Treatment options for wood

Treatment option	Comments
Reuse	Reuse of wood takes place today, particularly of pallets and wood packaging.
Direct recycling	Separated waste wood in principle may be recycled for a number of purposes.
Indirect recycling	Incineration with energy recovery.
Landfilling	Impregnated wood is landfilled, if it contains heavy metals.

1.12.2 Environment and resources

Wood is a renewable resource, and if it is incinerated it substitutes other energy sources. Upon reuse or direct recycling, energy for tree felling, transportation and processing is saved, and the resource can still substitute energy for heat etc. upon waste incineration.

Impregnated wood constitutes a particular environmental problem, and its use and waste quantities are increasing significantly. Wood impregnated with creosote and fungicides may be crushed and incinerated at high temperatures. However, if impregnation agents are heavy metals, controlled landfilling is required for environmental reasons. However, methods are being developed that may recover heavy metals by crushing and electrolytic treatment, after which residual materials may be incinerated.

Table 1.32: Significant environmental differences between landfilling, incineration and recycling of waste wood

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Wood R/I/L	xx					xx	x	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

For wood, a distinction must be made between clean wood and impregnated wood. Clean wood in waste is mostly used as an energy resource. However, pigmentation in paints may constitute a problem with toxic substances.

From an environmental point of view, for impregnated wood managing toxic substances used for impregnation is crucial. If substances can be rendered harmless through incineration it saves energy resources. If landfilling is necessary there is a long-term risk of release of, for example, heavy metals, to the surroundings.

1.12.3 Data basis

Table 1.33: Data sources for wood

ISAG system	Annual statistics	Statuses etc.
Quantities of wood in the ISAG system consist of both ordinary and impregnated wood collected for recycling. The rest of wood used is included in ”various burnable”, ”various unburnable” and ”other construction and demolition waste”		Some statuses have been made of consumption and treatment of impregnated wood by Waste Centre Denmark /3/.

Wood collected for reprocessing is included as an ISAG fraction.

Waste Centre Denmark has published statistics on production, consumption and treatment of impregnated wood /3/. Calculations of amounts of wood for treatment are difficult, as many years may pass from use to waste treatment.

1.13 Soil and stone

1.13.1 Treatment options

For soil and stone the following treatment options are possible:

Table 1.34: Treatment options for soil and stone

Treatment option	Comments
Reuse	Backfilling and covering at landfills, if it is not contaminated.
Direct recycling	By remediation, if it is contaminated
Indirect recycling	
Landfilling	If it cannot be cleaned

1.13.2 Environment and resources

Direct recycling upon remediation for oil contamination, for example, takes place in either stationary or mobile plants or by treatment without excavation. In the use of mobile plants and treatment without excavation, energy consumption for transportation is reduced.

Treatment options range from bacteriological treatment, washing, heating or incineration, and energy and environmental issues associated with these treatment options differ widely. The choice of treatment option also depends on the type of contamination.

Without going into detail on treatment options, it may be concluded that excavation and transportation to treatment plants is expensive and energy-intensive. In return, the most significant contamination is removed and this would otherwise be washed out into groundwater. Excavating and landfilling contaminated soil requires secure facilities of a considerable size, and consequently soil remediation is definitely the preferred option.

In on-site treatment, with or without excavation, much transportation energy can be saved compared to treatment at stationary plants. On-site treatment options are not always sufficiently efficient or fast, and consequently transportation to a treatment plant is often preferred.

Table 1.35: Significant environmental issues for incineration compared to recycling soil and stone.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophicatio n	Local: ozone (smog)	Tox eco/ hum		
Soil etc. R/L	x					xx	xx	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

The most significant environmental problem associated with treatment of contaminated soil is the risk of release of toxic substances to the surroundings. Upon landfilling space is taken up, and if soil is contaminated with heavy metals, the problem is merely postponed.

Upon remediation of soil, transportation to a treatment plant will require energy, and furthermore some treatment options are energy-intensive.

1.13.3 Data basis

Table 1.36: Data sources for soil and stone

ISAG system	Annual statistics	Statuses etc.
Quantities of ”soil and stone” only cover contaminated soil for landfilling or soil cleaning as well as clean soil for covering.	The different soil treatment plants may be able to state amounts treated annually, but such information is not published in compiled form.	Contaminated soil is covered by the Soil Contamination Act, aiming among others to survey all sites with contaminated soil (does not include sites with diffuse contamination).

Both clean soil used for covering and exempt from taxation and taxable soil for remediation or landfilling are included in the ISAG system. By contrast, clean soil for disposal in gravel pits is not included.

1.14 Other recyclables

1.14.1 Treatment options

This group covers waste for subsequent separation and treatment, for example scrapped vehicles or dry household waste.

Table 1.37: Treatment options for "other recyclables"

Treatment option	Comments
Reuse	
Direct recycling	Upon separation in different fractions and subsequent reprocessing
Indirect recycling	Dry household waste can be incinerated, thus recovering energy contents.
Landfilling	

1.14.2 Environment and resources

Manual separation of recyclable dry, but mixed household waste entails so many working environment problems that it is not carried out in Denmark. Instead, mechanical crushing and drying of waste may be carried out, and waste can subsequently be pressed into a so-called "dry-stabilate" to be transported, stored and used for subsequent incineration.

The other large item in this fraction is vehicle scrap in temporary storage. This fraction is currently treated after shredding and further reprocessing of metal parts. The large problem associated with this option is shredder waste consisting mostly of mixed plastics that is today landfilled, as incineration gives severe risk of contamination with a number of organic and heavy-metal-containing compounds.

Table 1.38: Significant environmental issues for landfilling compared to recycling of other recyclables.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Other recyclables	xx	xx				xx	x	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

The fraction consists of dry household waste, which is temporarily landfilled, as well as vehicle scrap, particularly shredder waste, for subsequent treatment. Energy and resource problems associated with subsequent treatment of waste products will be in focus here.

Since landfilling is temporary, this is not the most decisive environmental issue. After separation there may be a residual fraction that is re-registered in the ISAG into waste suitable for incineration.

Vehicle scrap may contain environmental contaminants such as waste oil, cooling and brake fluids. Upon reprocessing of vehicle scrap by shredding there will be a resource benefit. However, there will be a residual fraction, particularly of mixed waste plastics, that may cause a toxic impact on the environment upon incineration or landfilling. As no acceptable treatment options are available today, shredder waste is temporarily landfilled.

1.14.3 Data basis

Table 1.39: Data sources for materials for recycling landfilled temporarily.

ISAG system	Annual statistics	Statuses etc.
Amounts landfilled temporarily for subsequent recycling are registered. Waste removed for reprocessing is registered in the ISAG system.		

The ISAG system contains data on temporarily stored amounts that are recyclable. Since summer 2000 there has been a special premium and subsidy scheme for end-of-life vehicles as well as an approval scheme for plants receiving vehicle scrap.

1.15 Health-care risk waste

1.15.1 Treatment options

This group consists of waste with a risk of infection. The only relevant treatment option therefore is incineration, with or without energy recovery.

Table 1.40: Treatment options for health-care risk waste

Treatment option	Comments
Reuse	
Direct recycling	Separation is possible in principle for a number of materials.
Indirect recycling	Incineration with energy recovery.
Landfilling	

1.15.2 Environment and resources

Incineration, particularly of PVC-containing materials will cause environmental problems. For all resources in this fraction a 100% loss takes place, but to some extent energy is recovered upon incineration.

Minimisation of waste quantities and choice of less environmentally harmful materials instead of PVC seem to be the only alternatives at present. Waste quantities in question are relatively small.

Table 1.41: Significant environmental issues upon incineration of health-care risk waste

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Health-care risk waste	xx					x		

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Energy recovery from waste incineration is the most important issue in waste management. Upon incineration of PVC toxic substances may be formed, which however can be limited through optimisation of the incineration process.

1.15.3 Data basis

Table 1.42: Data sources for health-care risk waste

ISAG system	Annual statistics	Statuses etc.
Registers waste led to special treatment as health-care risk waste.		

The ISAG system registers quantities of health-care risk waste from hospitals, nurseries and clinics etc.

1.16 Mixed waste for incineration

1.16.1 Treatment options

This is one of the largest fractions registered in the ISAG system. It covers a large proportion of domestic waste and most other waste led to incineration.

Table 1.43: Treatment options for mixed waste for incineration

Treatment option	Comments
Reuse	
Direct recycling	
Indirect recycling	
Indirect recycling	Incineration, gasification, composting
Landfilling	

1.16.2 Environment and resources

Manual separation of recyclable dry, but mixed household waste entails so many working environment problems that it is not carried out in Denmark. But it is possible to increase source separation and collect more paper for reprocessing /30/.

If waste is collected in a mixed state, mechanical crushing and drying of waste may take place instead, and waste can subsequently be pressed into a so-called ”dry-stabilate” to be transported, stored and used for subsequent incineration.

Even if trials have been made with gasification and composting of mixed domestic waste, residues from this treatment still constitute an environmental problem. Such treatment options are mostly practised for the source-separated, organic part of waste where the residual product is much more suitable for use as compost. If waste is stored without treatment (or is landfilled) the material will start gasifying, leading to methane gas being emitted to the surroundings.

Table 1.44: Significant environmental issues upon incineration compared to recycling of burnable household waste

	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Burnable I/R	xx	xx	xx	Xx		x	xx	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

In the assessment of resource and environmental advantages from incineration, both landfilling and incineration of waste must be compared with fuel consumption and environmental impacts from energy generation without waste incineration.

The most significant environmental problems associated with waste for incineration that do not necessarily arise in generation of the energy that is substituted are:

- Resource loss of incinerated materials, as only iron is recycled after incineration
- Emission of methane gases contributing to global warming
- Emission of acidifying substances such as NOx, HCl, etc.
- Emission of toxic substances such as heavy metals and persistent organic compounds or presence of such in residues.
- Landfill requirement for residues

1.16.3 Data basis

Table 1.45: Data sources for mixed waste for incineration

ISAG system	Annual statistics	Statuses etc.
Registers quantities received for incineration, from both households and industry.		”Domestic waste from private households” /5/ is the most recent status of composition of domestic waste from households.

The ISAG system registers waste quantities received at waste incineration plants. A more detailed statement of composition of waste may be found in

”Domestic waste from private households” /5/. This publication presents results of a separation trial of a number of domestic waste bags in 1992/93.

The Association of Danish District Heating Plants publishes an annual statement analysing energy resources by waste incineration and other sources at the different plants /2/. In the assessment of substitution of energy with waste incineration such information is essential. However, statistics do not contain information on waste heat from waste incineration that is not recovered.

1.17 Mixed waste not suitable for incineration

1.17.1 Treatment options

This group consists of waste separated from industrial waste and bulky waste that is not suitable for incineration. It may be burnable waste that is not incinerated for environmental reasons, such as shredder waste, or it may be unburnable waste.

Table 1.46: Treatment options for waste not suitable for incineration

Treatment option	Comments
Reuse	
Direct recycling	
Indirect recycling	
Landfilling	Entire fraction is landfilled today

1.17.2 Environment and resources

This is mixed waste for which no suitable treatment option exists today. This material cannot be used for backfilling, and therefore an essential environmental parameter is space for landfilling. The material is relatively stable, as it contains no organic materials in significant quantities, but its composition has not been studied sufficiently for assessing how fast the different components are decomposed. The material contains a number of environmentally harmful substances, such as heavy metals in additives for plastics.

Perspectives for future treatment may include better separation and incineration methods for some parts of this waste.

Table 1.47: Significant environmental issues for landfilling compared to recycling of mixed waste not suitable for incineration.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Unsuit-able L/R		xx				x	xx	x

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Separation of this waste may save resources, and the need for landfilling may be reduced. This may reduce the risk of release of toxic compounds. Working environment issues associated with better separation have not been studied sufficiently.

1.17.3 Data basis

Table 1.48: Data sources for waste not suitable for incineration

ISAG system	Annual statistics	Statuses etc.
Registers waste quantities not suitable for incineration led to landfilling.		

Waste is registered as a fraction in the ISAG system, and no further analyses of waste composition are known of.

1.18 Sludge

1.18.1 Treatment options

Sludge from wastewater treatment plants and industry may in principle be treated in the following ways:

Table 1.49: Treatment options for sludge

Treatment option	Comments
Reuse	
Direct recycling	Composting and spreading on farmland
Indirect recycling	Gasification or incineration with energy recovery
Landfilling	If limit values are not complied with, sludge is landfilled

1.18.2 Environment and resources

The largest problem associated with sludge is its contents of environmental contaminants such as heavy metals and eco-toxic organic compounds such as decomposition residues from tensides etc. Substances derive from sewage from industry and households. Requirements for contents of substances in sludge before spreading on farmland are becoming increasingly strict, whereas it seems difficult to reduce contents of environmental contaminants in wastewater. This means that an increasing amount of sludge is landfilled instead of being used as a soil improver and nutritious material.

Sludge may be treated by composting or gasification before spreading on farmland, but it still requires a low content of environmental contaminants, unless sludge is landfilled after gasification.

Upon gasification, energy contained in sludge is recovered, which counts on the positive side in a life-cycle perspective, as the fertilising value of sludge can still be exploited. However, there will also be a certain emission of methane gas – either from storage of sludge or in connection with the gasification process. Methane gas contributes to global warming.

Upon incineration of sludge, the fertilising value is lost. By contrast, some of the environmental problems of landfilling may be minimised or removed. The incineration process normally gives only a small energy surplus, as evaporation of water contained in sludge requires much energy. Furthermore, it is difficult to achieve incineration that does not cause serious environmental problems relating, for example, to PAH, just as the contents of heavy metals in sludge are merely removed to the flue gas from the incineration process.

Table 1.50: Significant environmental issues for incineration or landfilling compared to recycling sewage sludge.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Sludge R/I/L			Xx	x	x	xx	xx	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

The critical issue for sewage sludge is whether it contains toxic compounds that makes it unsuitable for spreading on farmland.

Incineration is another treatment option, entailing instead a risk of problems of CO2 and PAH emissions without any significant energy benefit, as most energy will be used for drying sludge. If sludge is stored, gasified or composted, it will release methane gases contributing to global warming.

1.18.3 Data basis

Table 1.51: Data sources for sludge

ISAG system	Annual statistics	Statuses etc.
Sludge from industry is registered in the ISAG system.		Sewage sludge from municipal and private treatment plants in 1997 /31/

Sludge is registered in the ISAG system and in individual registration of sludge from wastewater treatment plants. Sludge quantities and contents of environmental contaminants have been surveyed in detail in recent years.

1.19 Sand and screenings

1.19.1 Treatment options

Treatment residues from wastewater treatment plants – various waste from pre-filtering and precipitated sand.

Table 1.52: Treatment options for sand and screenings

Treatment option	Comments
Reuse	
Direct recycling	Backfilling
Indirect recycling	

Landfilling	Landfilling

1.19.2 Environment and resources

As long as it is possible to separate into further fractions, such as metal, burnable materials and sand, it will be possible to recycle some resources and save landfilling space. No detailed survey of the composition of this fraction is known of.

Table 1.53: Significant environmental issues for landfilling compared to recycling of sand and screenings

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophicatio n	Local: ozone (smog)	Tox eco/ hum		
Screen-ings etc. L/R							xx	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

This waste is landfilled today, and the environmental focus is on landfill requirements.

1.19.3 Data basis

Table 1.54: Data sources for sand and screenings

ISAG system	Annual statistics	Statuses etc.
Registered in the ISAG.		

Data appears from the ISAG system, but constitutes only a small quantity.

1.20 Slag, fly-ash and flue-gas cleaning products

1.20.1 Treatment options

The following covers all residues from waste incineration plants and coal-fired power plants.

Table 1.55: Treatment options for slag and fly-ash etc.

Treatment option	Comments
Reuse	
Direct recycling	Backfilling and road construction.
Indirect recycling	Aggregate for concrete. Raw material in plaster board. Sulphuric acid.
Landfilling	Coastal landfills.

1.20.2 Environment and resources

Slag from waste incineration plants is used extensively for backfilling /40/, but due to contents of heavy metals it must be ensured that no leaching to groundwater takes place. In contrast, flue-gas cleaning products are not sufficiently stable to be recycled and are temporarily landfilled either in Denmark, Norway or Germany. Trials are taking place to stabilise residues, and when a method has been found residues can be landfilled permanently. This will save energy resources for transportation and management of materials.

Table 1.56: Application of residues from coal-fired power plants (The Danish Environmental Protection Agency, 1997)

Recovery in 1997 of residues from coal-fired power plants. ('000 tonnes)	Fly ash	Slag/ bottom ash	Gyp sum	DDP*	Sulph. acid	Total
Cement	311					311
Concrete	220					220
Porous concrete	7					7
Asphalt	49					49
Roofing felt	5					5
Backfilling cf. Statutory Order 568	34	111				145
Backfilling cf. Part 5 approvals (Env. Protec. Act)	169	5				174
Granulates				4		4
Fertiliser					8	8
Backfilling				36		36
Plaster board			306			306
Total	795	116	306	40	8	1,265

* DDP: Dry desulphurisation product
Source: Waste 21. Note that the table does not cover residues from waste incineration plants

Residues from coal-fired power plants account for very large quantities that are, however, decreasing. The recycling rate for the different residues is very high. Table 1.56 shows quantities recycled in 1997. Only 27% was landfilled, and the objective in Waste 21 is that landfilling should cease before 2004.

Table 1.57: Significant environmental issues for landfilling compared to recycling of slag etc.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Slag etc. R/L		xx				xx	xx	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

Upon recycling of residues, energy and resources for manufacture of similar materials from virgin materials (sand and gypsum) are saved, and landfill space for residues is saved.

For slag and residues from incineration, contents of heavy metals are often too high for them to be recycled in the same way as residues from power plants. If possible, slag is used for backfilling in roads etc., but it is often landfilled after separation of metals for recycling.

1.20.3 Data basis

Table 1.58: Data sources for slag and fly-ash etc.

ISAG system	Annual statistics	Statuses etc.
Registers slag from waste incineration plants. Power plants register waste quantities from power and heat generation.		Waste Centre Denmark informs that agreements have been made for removal of slag from waste incineration plants covering a total of 80,000 tonnes per year /38/

Data appears from the ISAG system divided into slag, fly-ash and flue-gas cleaning products from waste incineration and residues from coal-fired power plants. As early as in 1997 around 75% of residues from power plants and waste incineration were recycled /37/. Flue-gas cleaning products from incineration are landfilled as hazardous waste.

1.21 Dust-emitting asbestos

1.21.1 Treatment options

Table 1.59: Treatment options for dust-emitting asbestos

Treatment option	Comments
Reuse	
Direct recycling	
Indirect recycling	
Landfilling	Encapsulation prior to landfilling

1.21.2 Environment and resources

Asbestos is non-decomposable waste. Asbestos is divided into three categories, of which dust-emitting asbestos (Category 1), due to the dangers to health from dust, is encapsulated (normally with plastic film) to allow for management and transportation to final disposal. Upon landfilling this material is very stable, and there is very little risk of leaching of environmentally harmful substances.

Table 1.60: Significant environmental issues upon landfilling of dust-emitting asbestos.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
Asbestos L							xx	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

After landfilling asbestos will not cause significant environmental impacts.

1.21.3 Data basis

Table 1.61: Data sources for dust-emitting asbestos

ISAG system	Annual statistics	Statuses etc.
Registered as individual fraction. Dust-emitting asbestos is landfilled.		

Appears from the ISAG system, but constitutes very small quantities.

1.22 Oil and chemical waste

1.22.1 Treatment options

This fraction consists of a number of waste products. Oil and chemical waste is discussed in this report as an individual fraction, corresponding to the former systematics of the ISAG system. Since the Statutory Order on Waste from 1998, waste has been registered in far more detail than hitherto. Today around 50% is treated at the hazardous waste treatment plant of Kommunekemi.

Table 1.62: Treatment options for oil and chemical waste

Treatment option	Comments
Reuse	
Direct recycling	Recycling of lead, nickel and cadmium from batteries. Cleaning of waste oil for recycling, for example for heating purposes.
Indirect recycling	Incineration with energy recovery.
Landfilling	Certain residues are landfilled, for example radioactive wastes.

1.22.2 Environment and resources

Consists of a large number of environmental contaminants of which only a few are reprocessed for recycling – particularly batteries containing lead, nickel and cadmium where resources can be recycled. Thus, landfilling of heavy metals is avoided, and the loss of resources is reduced.

To a certain extent waste oil is cleaned for recycling. However this can only be done for some fractions of waste oil. Some waste oil is cleaned for water and can subsequently be utilised at district heating plants.

Upon incineration of waste oil and other chemicals at Kommunekemi with subsequent flue-gas cleaning and special landfilling of slag, waste heat is used for heat and power generation.

Table 1.63: Significant environmental issues for incineration compared to recycling of oil and chemical waste

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophicatio n	Local: ozone (smog)	Tox eco/ hum		
Oil and chem. waste. R/I	xx	xx				Xx		

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

A very large proportion of oil and chemical waste causes toxic impacts on the environment. As the group is large, consisting of many substances and products, only a few specific environmental issues will be discussed here.

For lead and Ni/Cd accumulators a collection scheme has been established, ensuring recycling of resources and avoiding spreading of heavy metals in the environment.

Cleaning and combustion of waste oil gives an energy benefit. A number of surveys have been launched with a view to recycling different fractions of hazardous waste.

1.22.3 Data basis

Table 1.64: Data sources for oil and chemical waste

ISAG system	Annual statistics	Statuses etc.
Reports, particularly from Kommunekemi.		

Data appears from the ISAG system. Since 1998 hazardous waste has been classified and registered in far more detail than hitherto. In waste statistics 1999 /40/ hazardous waste is now registered in 60 to 70 categories, and the Statutory Order on Waste contains even more categories /35/.

1.23 Electrical equipment

1.23.1 Treatment options

This group consists of two types of product that are discussed under one group in this report: Electrical and electronic equipment (EEE) and refrigeration equipment. Both groups are covered by special waste management schemes.

Table 1.65: Treatment options for WEEE (Waste electrical and electronic equipment)

Treatment option	Comments
Reuse	Some components of white goods, for example, may be reused after disassembly.
Direct recycling	Equipment is disassembled, partly manually, shredded and reprocessed. Today this is only done for some equipment, including refrigeration equipment, with a view to collection of CFCs. In future this must be extended to electronic equipment.
Indirect recycling	Small appliances often end up in incineration, for example mixed with domestic waste – even if this is inappropriate.
Landfilling	Used extensively today, and is expected to be reduced as collection schemes for WEEE are extended.

1.23.2 Environment and resources

Electrical equipment contains a number of different plastic, glass and metal parts as well as electronic components. In addition, refrigeration equipment marketed in Denmark before 1994 may contain ozone-depleting CFCs.

Refrigeration equipment can be disassembled, and CFCs from the cooling system and insulation material can be collected. Metal parts can then be sent for recycling or shredding together with other metal scrap. In this process, metal parts are separated from plastic parts.

For electronic components, new requirements for take-back and reprocessing aim at dismantling appliances. Cathode ray tubes and a number of electronic components must subsequently be treated at specialised plants, whereas metal parts can be reprocessed together with metal scrap. Plastic parts may contain brominated flame retardants or be made of PVC, both causing dioxin formation upon incineration.

Table 1.66: Significant environmental issues for incineration or landfilling compared to recycling of WEEE.

Fraction Typical treatment	Energy (incl. contri-bution from subst.)	Re-sources *	Environmental impacts *				Land-filling *	Working environ-ment*
			Global: global warming/ ozone layer	Regional: acidification/ eutrophication	Local: ozone (smog)	Tox eco/ hum		
WEEE R/L		xx	xx			xx	xx	

*) All resource consumption and environmental impacts excl. contribution from energy consumption
xx: significant, x: less significant, nil: insignificant

For refrigeration equipment there is a large risk of release of ozone-depleting substances - CFCs.

For electronics in general there is a risk of release of heavy metals and persistent substances such as PCBs from electronic components.

In addition, products contain a number of relatively rare metals that are lost upon landfilling. Upon reprocessing of electronic components these metals may be recovered.

1.23.3 Data basis

Table 1.67: Data sources for electrical equipment

ISAG system	Annual statistics	Statuses etc.
The ISAG system registers refrigeration equipment and separately collected WEEE. A large part is led to incineration and landfilling today /37/		The industrial organisation for offices and IT has made a statement of developments of WEEE /38/. The composition of WEEE is not analysed in detail /38/

Data appears from the ISAG system. From 1998 and 2000 current statements will be made of refrigeration equipment and WEEE covered by the take-back scheme.

Time consumption for comprehensive mapping

2 Quantities and treatment of different waste fractions

Below, the possibilities of setting up general calculation principles for estimates of waste quantities within the different material fractions will be discussed. In addition, the amount of time required for this purpose will be considered. To get an overall outline of the amount of time required for a mapping, considerations on time requirements for provision of LCA data will be included, see also Chapter 6 of the main report.

Mixed waste fractions, such as "domestic waste", consisting of a number of material fractions will be represented in calculations under the different materials and are not discussed as individual waste fractions. As a check of calculated quantities, total quantities of all material fractions must correspond to total registered waste quantities, incl. mixed fractions.

It is assessed that a distinction can be made between the following material fractions:

- Paper and cardboard
- Glass
- Plastics – divided into types of plastics
- Metal - divided into types of metal
- Oil and chemical waste – possibly divided into main groups
- Automobile rubber
- Concrete
- Tiles
- Asphalt
- Wood - divided into plates and "other wood"
- Other building materials
- Food waste/other organic
- Garden waste
- Soil, gravel and stone
- Other materials (such as ceramics, rubber (excl. automobile rubber), textiles)

A decisive factor for the calculation of indicators is whether data is only used for quantities actually recycled (for example calculation of savings realised), or whether data for total waste quantities is used, in the main report referred to as Model A and Model B respectively.

Appendix A contains an environmental screening of the different waste fractions. In the following, a review will be presented divided into material fractions with a view to estimating the amount of time required for provision of data for calculation of the proposed indicators.

2.1 Review of material fractions

2.1.1 Paper and cardboard

Collection and recycling
Annual statements of paper consumption and collection and recycling of paper appear from the statistics on waste paper from Waste Centre Denmark /39/.

Other treatment
Waste paper that is not recycled can be estimated based on statements in the above statistics. Therefore, it is assessed that there is no need for further statements of consumption of paper and cardboard.

2.1.2 Glass

Collection and recycling
Annual statements of consumption of glass packaging and collection and recycling of glass packaging appear from the statistics ”Glass, bottles and cullet” from Waste Centre Denmark /18/. No statement of recycling of flat glass is available.

Other treatment
Waste glass packaging that is not recycled can be estimated on the basis of the statements in the above statistics. Therefore, it is assessed that there is no need for further statements of consumption of glass packaging. For flat glass there will be a need for a status, and this will take about ¼ to 1 man-week. It is assessed that the status should be updated every five to ten years.

2.1.3 Plastics

Collection and recycling
In the plastic packaging statistics, figures are available for collection of plastic packaging divided into the plastic types: LDPE, HDPE, EPS, PP, PET, PS and "Other plastics " /28/. In addition to packaging, there is recycling of production waste and to a minor extent of PVC. No statistics are available for these quantities that must be based on statuses.

Other treatment
The rate of collection, and thus quantities of plastic packaging not collected for recycling, is calculated in statements by comparing quantities collected with the supply of plastic packaging. This is possible, as the useful life of plastic packaging is so short that quantities becoming waste will correspond almost completely to consumption. For plastic packaging, thus, necessary data is directly available. For each plastic type it will be relatively easy to develop specific indicators that primarily based on energy consumption for production of the plastic type in question.

At European level plastic packaging constitutes around 57% of total quantities of plastic waste, incl. PVC /28/. For other waste plastic types, no current statistics are compiled, but these plastics – apart from production waste and PVC for building purposes – are almost exclusively incinerated or landfilled today.

”Other plastics”, accounting for around 43% of total plastic quantities, consists of a large number of different plastic types that are very different as to energy consumption for production. For example, for the production of polyamide (nylon) around 130 GJ/tonne are consumed, whereas manufacture of polypropylene only consumes 30 GJ/tonne /15/. This means that ”other plastics” in relation to indicators probably accounts for a larger part of the contribution from plastics than the 43% it constitutes quantitatively. Plastics to a large extent will derive from imported products such as electronics and vehicles.

It will hardly be possible to make annual statements, but composition of plastics may be estimated roughly on the basis of data from the Association of Plastics Manufacturers in Europe (APME). However, in all circumstances a more detailed survey of average composition of plastics will be necessary. Quantities of collected and recycled PVC will also have to be found in individual studies, as no annual statements are made.

At first it is estimated that it will be relevant to divide amounts into polyolefin (PE and PP), PVC, polystyrene (such as PS, XPS and EPS), PET/PBT, PUR (polyurethane) and other cast plastics (epoxy, phenol resins and polyester). In setting up the calculation principle it will be necessary to evaluate whether this division is expedient.

Detailed statuses of quantities of plastics for waste treatment are estimated to have scope per plastic type (or group of plastic types such as composite materials) corresponding to the mass-flow analyses carried out for metals. As there is only very little recycling apart from packaging plastics, however, statements will be simplified by the fact that for most types it will be sufficient to state total waste quantities without making a detailed distinction between treatment options and use of plastic products. An overall individual survey of use and treatment of the most important plastic types will require around 4 to 12 man-months. It is assessed that such a survey should be conducted every five to ten years.

It should be noted that statements for ”other plastics” compared to statements for packaging plastics require a more detailed analysis, as the useful life for products is so long that it cannot be assumed that quantities for waste treatment in a given period corresponds to consumption.

2.1.4 Metals

As it appears from the example calculated, metals have significant weight in the total accounts.

Collection and recycling
In the ISAG statistics, all metals are listed together under ”Iron and metals”. The total metal fraction consists mainly of iron and steel, and a statement of quantities and treatment of the individual metals therefore must be based on other data sources.

It is relevant to divide into:

- Iron and steel (excl. stainless steel)
- Aluminium
- Copper
- Stainless steel (covering the major part of chromium and nickel)
- Lead
- Zinc

Other metals will only account for a very small part of total quantities. If the number of metals is to be reduced it would be most obvious to leave out lead and zinc.

For estimating quantities of metals recycled it will be necessary – similar to the aluminium example of Appendix C – to base statements on Statistics Denmark's figures for imports/exports of scrap and production of secondary metals. Under the different code numbers in the imports/exports statistics composite products appear, so there will be some uncertainty associated with such a statement. For example, cables are found under "copper scrap", and mixed fractions of heavy metals from shredder plants are found under "zinc scrap". In the preparation of a general methodology this uncertainty can be reduced by stating the estimated rate of each metal for each code number.

Quantities remelted in Denmark are stated in the statistics for aluminium and steel. The uncertainty for this code number is relatively small. For lead there is more uncertainty associated with quantities remelted, as they to not appear directly from statistics. But quantities are very small compared to total quantities recycled. For other metals there is no significant production of secondary metals in Denmark.

As seen in the example of aluminium, the uncertainty of the statement in the mass-flow analysis has been assessed at ± 12%. In a statement based on general principles of calculation uncertainty must be expected to be somewhat larger for most metals. So it will not be possible to follow small changes from one year to the next, but only to see development trends over a longer period.

It is probably possible to set up a regular procedure allowing for an estimate of total quantities recycled on the basis of an extract from Statistics Denmark. Changes take place occasionally in the division of code numbers, so it will be necessary to check every year that calculations actually cover the relevant code numbers. In a rough estimate, it will require 1 man-week to set up a calculation principle for all metals. Subsequently, every year it will take around ½ to 1 man-day to collect data from Statistics Denmark.

Other treatment

For quantities incinerated or landfilled it is not possible to set up general calculation principles based on available statistics. Thus, it will be necessary to start with the most recent mass-flow analyses. For aluminium, copper, stainless steel (mass-flow analysis for nickel) and lead, analyses for 1994 are available. For iron and steel quantities for landfilling are so small that they may probably be neglected. For zinc no mass-flow analysis is available. It is relatively time-consuming to update mass-flow analyses, so it should be expected to use the same values for a number of years.

It might be considered to keep total quantities of metals constant, whereas quantities for incineration or landfilling are estimated as the difference between this quantity and quantities recycled. However, for most metals this difference is so small compared to uncertainties, that uncertainties associated with the difference would easily be ± 50% or more. Therefore, there seems to be no other possibility than to use statements in mass-flow analyses of quantities for incineration and landfilling respectively. In this way, significant changes in indicators (apart from ”savings realised”) can only be found through a revision of estimates of the mass-flow analyses.

The time required for preparing a detailed mass-flow analysis is in the range of 4 to 6 man-months for one single metal. If the purpose is only to estimate waste quantities divided into treatment options, the analysis may probably be carried out in less time, but 1 to 3 man-months per metal would still be necessary. The reason is that waste quantities must be estimated on the basis of a thorough knowledge of historical use of metals for all application areas. For most metals there are many minor sources of waste. For the heavy metals lead, cadmium and mercury it has been practice in the last decades to update mass-flow analyses every five to ten years. For zinc no analysis is available, whereas for other metals only one detailed analysis is available so far.

The amount of time required for updating quantities every five to ten years for all metals is 7 to 14 man-months, according to a rough estimate. It should be noted that updating mass-flow analyses can also take place as a part of other surveys, and that the time needed specifically for the calculation of indicators may thus be reduced.

2.1.5 Oil and chemical waste

Collection and recycling
Precise statements of both total waste quantities and quantities of recycled oil and chemical waste are available. As indicators do not cover environmental impacts, it will be possible to group oil and chemical waste in large groups and thus minimise work of developing LCA-based indicators. Resource consumption for production of oils and chemicals will primarily relate to energy resources, making it simpler to group several categories.

Other treatment
A minor part of oil and chemical waste is not treated as ”oil and chemical waste”, but it is assumed that such small quantities are involved that they can be disregarded.

Oil and chemical waste will only cover part of total consumption of chemicals, as chemicals ending up in finished products will not be part of the statement. It is estimated to be unrealistic to make statements covering these chemicals.

2.1.6 Automobile rubber

Collection and recycling
The ISAG system contains information on total quantities of automobile rubber collected. As tyres today must be collected separately it is assumed

that statistics cover quantities actually treated, and that relatively small quantities are treated in other ways. ISAG statistics may be supplemented with the tyre trade's statistics of the take-back scheme and statistics of retreading and granulation of rubber powder /40/. Large tyres (trucks and tractors etc.) have only been covered by the rules, and thus statistics, from 1999. The decisive factor in the calculation will be to ”value” materials substituted in recycling.

Other treatment
Small quantities of automobile rubber are assumed to be treated as bulky waste or shredder waste. At present no statement is available, and thus quantities will have to be estimated on the basis of a status. As a rough estimate, such a status will require ½ to 1 man-week.

2.1.7 Concrete, tiles and asphalt

Collection and recycling
Quantities of concrete, tiles and asphalt recycled appear from the ISAG. In direct reuse of asphalt for new paving on site, treated quantities need not be reported to the ISAG. Waste Centre Denmark has carried out a more detailed survey of management of construction and demolition waste /32/.

Other treatment
Material-flow statistics are special statistics that are also prepared for construction and demolition waste /32/. Quantities generated annually also appear from these statistics, providing the basis for calculating how large a proportion of construction and demolition waste is recycled. In 1997 more than 91% was recycled as backfilling material.

Overall, there will only be a very small uncertainty in statements of quantities and waste treatment, and it is estimated that there is no need for further statements. The decisive factor for these material fractions will be to ”value” materials substituted in recycling.

2.1.8 Wood (incl. wood plates)

Collection and recycling
Wood collected separately and registered in the ISAG primarily covers production waste and pressure-impregnated wood. Reuse carried out, for example, in demolition enterprises, will not be registered, but is estimated to account for a very small part of collected quantities of wood treated as waste. In an indicator system not covering toxicity it is estimated that there is no need for a division into impregnated wood and other wood.

Other treatment
There are no statements of quantities of wood and wood plates incinerated or landfilled. Quantities must be estimated based on statuses. As there is presumably no large difference between energy recovery upon incineration, or recycling of wood, for example into wood plates, uncertainties in these quantities will hardly have a large impact on the overall indicator calculation. Therefore, the status can be made as a relatively rough estimate. A significant part of wood removed from buildings will be removed by demolition enterprises, and it is assessed that total quantities can be estimated on the

basis of information from demolition enterprises and waste management companies. A rough estimate of total quantities will require about 1 to 2 man-weeks.

2.1.9 Other building materials

Other building materials cover plasterboard, insulation material, roofing slabs, flooring etc. At present there is no statement available of quantities treated by recycling or in other ways. Minor recycling of plasterboard takes place, but apart from this such waste is mostly landfilled.

A rough statement of quantities will have to be prepared. It is estimated that a rough statement for all materials can be made in ½ to 1 man-month.

2.1.10 Garden waste, food waste/other organic

Quantities of garden waste, food waste/other organic collected for recycling appear from the ISAG. In relation to the proposed indicators it will especially be relevant to distinguish between recycling for animal fodder and other recycling. This distinction is possible on the basis of ISAG data.

Total quantities of organic waste are not currently stated, but can be found in individual status reports. In relation to indicators for energy and resources, waste treatment of organic waste will hardly have a large impact. The calculation principle of calculating consumption for substitute materials is not assumed to apply to food waste. A status of quantities of garden waste, food waste and other organic waste is estimated to require ½ to 1 man-week.

2.1.11 Soil, gravel and stone

Soil, gravel and stone for recycling appears from the ISAG. In relation to the proposed indicators, treatment of soil, gravel and stone will hardly have a significant impact, and it is estimated that there is no need for further statements of these waste quantities.

2.1.12 Sludge, flue-gas cleaning products, incineration slag and energy recovery from incineration

Total quantities of sludge, flue-gas cleaning products and incineration slag disposed of by recycling and landfilling appear from the ISAG.

In a calculation covering all relevant treatment options for the different material fractions (Model A), incineration slag and energy recovery from incineration will be represented through the material fractions resulting in the generation of slag and energy. Therefore, they should not be included separately in the calculation.

In a calculation only covering recycling (Model B) it will only be relevant to include the quantities of incineration slag that are used for building and construction purposes and energy recovery from incineration. This avoids having to divide waste for incineration into the different material fractions. Total energy generation at incineration plants appears from the annual statistics on energy-generating plants from the Danish Energy Agency.

It is estimated that there is no need for further statements of these fractions.

2.1.13 Other

In the ISAG statements, a number of material fractions will only appear in mixed waste fractions, as in the waste management system there is very little collection and recycling of them. Materials in question are ceramics, textiles, rubber (excl. automobile rubber) etc.

The statements only cover main materials, whereas chemical products in main materials are not covered. Chemical products that may constitute a significant part of total waste quantities are paints/varnish, joint filler, putty, and printing inks.

Apart from rubber it will hardly be possible to recycle these materials significantly, and the question is how important it is to carry out the calculation. If there is an interest in having a measurement for energy and resource consumption for the manufacture of materials treated, however, it is relevant to include these materials.

If there is a wish to include the most significant main materials, a status must be prepared for each material group. It is estimated that rough statuses giving total quantities without a detailed division into areas of application can be carried out in ¼ to 1 man-month.

2.2 Total amount of time required

Information on data sources is in Table 2.1. It is seen that for a number of materials it will be necessary to supplement information from the ISAG with material-flow statistics or similar statuses of total quantities treated. It is estimated that statuses should be updated every five to ten years.

Time required for calculation of indicators will largely depend on whether a complete statement of waste impact (Model A in main report) should be made, or only a statement of savings realised (Model B).

It is estimated that carrying out statuses will account for the largest part of time required for setting up a total calculation principle and provision of quantitative data for making the first calculation (excl. life-cycle based factors). Total time required for updating statuses has been estimated in Table 2.2 to 12 to 30 man-months. In the first calculation some time can be saved if existing mass-flow analyses from 1994 are used, but as there is also a certain time requirement for setting up the overall calculation principle, the amount of time required is still estimated to be in the range of 8 to 20 man-months.

If a status has been made, the annual statement of savings realised (Model B in main report) is estimated to require around 1 to 1½ man-months. A significant part of the time is needed for collecting and checking data on metals from Statistics Denmark.

If no status has been made, Model B can still be carried out. However, in this case it will require 3 to 5 man-months plus 2 months for the LCA data, a total of 8 man-months for the first calculation.

Table 2.1:
Data sources for quantitative data [1)]

Material fraction	Collection for recycling excl. recovery in incineration plants [2)]		Incineration and landfilling	
	Data source	app. %	Annual statement	Statement every 5-10 years [3)]
Paper and cardboard	ISAG (++)	45	MFS (+)	
Glass	ISAG (++)	Pack: 65 Other: 0 ?	Packaging: MFS (+)	Other: statuses (+)
Plastics – divided into types	Packaging: ? Other: (-)	Pack: <10% Other: 2 ?	Packaging: MFS (+)	Other: statuses (+)
Metal – divided into individual metals	Based on trade statistics Fe, Al (+) Other: (-)	Fe: 98 Al: 70 Cu: 80 Cr: >70? Ni: 70? Pb: >90 Zn: ?		Mass-flow analyses or statuses (+)
Oil and chemical waste - may be divided into main groups	ISAG (++)	>90 ?	ISAG (++)	
Automobile rubber	ISAG (++) Other statistics	>90		Statuses (+)
Concrete	ISAG (++)	80-85	MFS (+)*)	
Tiles	ISAG (++)	80-85	MFS (+)*)	
Asphalt	ISAG (+), excl. recycling on site	80-85	MFS (+)*)	
Wood – divided into wood and plates	ISAG (++)	<10 ?		Statuses (+)
Other building materials	-	?	-	Statuses (+)
Food waste/other organic	ISAG (++)	app. 25%	MFS (+)	
Garden waste	ISAG (++)	?	MFS (+)	
Soil, gravel and sand	ISAG (++)	?		Statuses (+)
Other (e.g. ceramics, rubber, (excl. automobile rubber))	-	<10 ?	-	Statuses (+)
Slag	ISAG (++)	-	-	-
Energy recovery	Energy statistics	-	-	-
Flue-gas cleaning products (coal)	ISAG (++)	-	-	-
Sludge	ISAG (++)	-	-	-

(++) certain data, up to ± 10%
(+) less certain data, from ± 10% up to ± 15%
(-) uncertain data, more than ± 15%
MFS: Material flow statistics.
*) Statistics no longer prepared

1) ***The uncertainties stated express the authors' estimates of uncertainty*** of quantitative data that is calculated on the basis of sources stated, and not necessarily the uncertainty of the sources by themselves. For example, quantities of metal recycled are calculated on the basis of several code numbers in the Foreign Trade Statistics, and the uncertainty is associated with the fact that products covered by the code number also contain other materials.

2) States for each material fraction the assessed proportion of quantities disposed that is collected for recycling. "?" states that the proportion is a rough estimate and very uncertain.

3) Statuses and mass-flow analyses less than 10 years old are available for several metals, but there is no general rule as to update frequency of these analyses.

Table 2.2
Approximate amount of time required for carrying out statuses

Material fraction	First time and subsequently every 5 –10 years 1)
Paper and cardboard	-
Glass	¼ - 1 man-week
Plastics – divided into types	4 - 12 man-months
Metal – divided into individual metals	6 - 14 man-months
Oil and chemical waste - may be divided into main groups	-
Automobile rubber	¼ - 1 man-week
Concrete	-
Tiles	-
Asphalt	-
Wood – divided into wood and plates	1-2 man-weeks
Other building materials	½ - 1 man-month
Food waste/other organic, garden waste	½ - 1 man-week
Soil, gravel and stone	-
Other (e.g. ceramics, rubber, (excl. automobile rubber))	¼ - 1 man-month 2)
Total	12 - 30 man-months 3)

1) For some fractions statuses are available that may be used for the first calculation, so total time requirement will be lower.
2) For the group "other", the estimate for the different material fractions is very rough.
3) The more updated mass-flow analyses available, the less time required for the indicator calculation.
-) Data already available, or not relevant for indicator calculation.

Assumptions for calculations

3 Assumptions for calculations

In this appendix, data bases and other specific assumptions for the calculated examples of the waste fractions paper and cardboard, glass packaging (such as deposit-return bottles) and aluminium are discussed. Furthermore, assumptions for the LCA data that are new compared to EDIP/the EDIP PC tool database are established.

3.1 Paper and cardboard

3.1.1 Quantities and statistics

Paper, both in terms of consumption and recycling, is one of the materials contained in waste that are best covered by statistics, and for which annual updates are made. Around half of paper consumption is collected for recycling, and the remaining half is led to incineration.

Waste statistics break down paper into the following types:
- Newspapers and magazines
- Corrugated cardboard
- Other paper and cardboard
- Good quality paper

Total consumption is broken down by a number of paper types. However, it is not always possible to relate consumption directly to quantities collected, so as to state, for example, how much newspaper is recycled and how much is incinerated.

To allow for an assessment of results of paper recycling it is also relevant to know into what different paper types are recycled, as the principle for the statement of environmental impacts from waste management is a statement of primary resources consumed in recycling.

For example, recycling into paper such as writing paper of high quality will cause less consumption of new, bleached paper of high quality (wood-free), whereas recycling into egg boxes will substitute unbleached paper with large contents of wood. Since there are significant differences in resource consumption and energy consumption associated with the different paper types, loss of utility value of paper bulk depends on the extent of exploitation of the properties of paper fibres upon recycling.

Even if it were possible to answer the above questions with supplementary statistical surveys, it would still be difficult to provide data on manufacture of different paper types and different recycling processes. The issue has been discussed often in life-cycle analyses (such as /13/), but much of the data material is confidential and cannot be used in reports available to the public.

So the only possibility left is to use average figures covering all paper types with the uncertainty associated with such a solution. Paper quantities used in the calculation are stated in Table 5.1 of the main report. In this table, all types of paper collected for recycling have been aggregated.

Other paper waste has been calculated as the difference between used paper quantity and recycled paper quantity. In principle, all paper that is not recycled is incinerated. However, some tissue ends up in wastewater. In 1997, tissue accounted for around 6 % of virgin paper /39/. Due to lack of more qualified estimates, the calculation assumes a landfill share of 13% for paper that is not recycled. This rate corresponds to the proportion of household waste that was landfilled in 1993. In the calculation of potential for recycling paper, it has been assumed that the remaining 87 % can be collected potentially for recycling. In the above-mentioned source, the realistic potential has been estimated at 80%.

3.1.2 Incineration of paper

In Chapter 1.4, actual energy recovery for the different materials upon incineration in Denmark has been calculated. Where the figure is to represent an average for the energy benefit from incineration of waste in Denmark, calculations are based on the calorific value of materials that must be reduced by 30%. Materials' calorific value appears, for example, from /15/. If it is assumed that cardboard accounts for one third of paper and cardboard collected for incineration, this means that an energy recovery will be used amounting to 15 MJ - 30% = 10.5 MJ/kg corresponding to a credit of coal consumption of 420 g. Further, around 12% of landfill requirement saved for coal waste in connection with extraction will be included. Slag from coal combustion is recycled today at a rate of 100%.

3.1.3 Recycling processes

Upon recycling of paper and cardboard the same data basis has been used for the recycling process as in the EDIP, using 1.15 kg paper for 1 kg recycled paper. This means that if 1 kg waste paper is led to recycling, a recycling process for 0.87 kg finished paper should be included, incl. residual waste.

Upon recycling of paper and cardboard, there is also a loss of utility value every time paper fibres are led to recycling. For mixed paper types, the EDIP sets this loss at 20%. This means that 20% virgin paper should be added to the system upon recycling, and that this quantity of paper will become waste at some point. This is included in the indicator as waste for landfilling.

3.1.4 Sensitivity assessment of indicator values for paper and cardboard

The most essential uncertainty in indicators for paper is the fact that the composition of paper and cardboard for recycling and incineration cannot be stated. Some of the extremes, for example, will be the landfill requirement for paper and cardboard with filler materials. As filler materials can constitute up to 30%, landfilling after incineration can vary from 0 to 300 g/kg paper incinerated. Energy consumption can vary to a similar extent.

Another source of uncertainty is the lack of published data on paper manufacture. In this respect, it can be decisive for the result of the statement, whether for example energy in the form of wood, hydropower or coal is used. Particularly the resource indicator will depend strongly on this point.

One of the general and very important elements of the resource factor is how to normalise and weight the different resources. In this project, factors of the EDIP project have been used, supplemented with new values in the areas where data is not included in the EDIP. In the preparation of the new values the same statement principles as in the EDIP have been used. General experience shows that normalisation and weighting factors are very significant for the result. However, no general estimate of the uncertainty associated with the resource factors used has been made.

3.2 Bottles and glass for packaging

3.2.1 Quantities and statistics

Statistics for bottles and glass are very detailed and have been prepared annually since 1989/1990. Most recent statistics derive from Waste Centre Denmark /18/, and give figures back to 1989.

Statistics cover bottles and glass packaging, but not crushed flat glass and glass found in incandescent lamps. In addition, bottles from the Danish deposit-return scheme are not included in the statement. Statistics on this consumption are available from other sources than the ISAG, and it is possible to include this glass quantity in an overall statement of consumption and recycling of glass, if so wished. The purpose of the trial, however, has been to test the calculation method, and in this context it has not been relevant to include additional information.

3.2.2 LCA processes and data sources

The EDIP project uses relatively old figures concerning the manufacture of virgin glass that have been verified, however, in a can/bottle project from 1998 /24/ with figures from the glass manufacturer Holmegård from 1992. Therefore, these figures have also been used for the indicator calculation. But with data from the recently published LCA statement of Danish generated power and heat in 1997 it will be possible to update data for energy consumption for glass melting. This also applies to remelting cullet. A 100% recovery of waste glass has been assumed, where the EDIP uses a 1% loss. However, separated waste glass in the ISAG is stated separately and is found in the present calculation as waste for landfilling. Waste separated for recycling is thus recycled at a rate of 100%.

For washing of bottles, information from the can/bottle project has been used /24/. Here, only data for energy consumption analysed between electricity and natural gas has been used, as well as information on the proportion of bottles crushed in the process and becoming waste. 2.5% virgin glass has been calculated for substitution of crushed bottles. However, cullet for landfilling has not been included, as it is assumed that it is led directly to remelting.

The EDIP project uses a loss of utility value of 10% for each remelting of glass. The loss of utility value is included in recycling of cullet for remelting, where 10% of virgin glass is added to glass recycled as loss of utility value, and the same quantity is included as loss upon landfilling. Just as the other losses of utility value used in the EDIP, estimates are relatively rough, and subsequent assessments will most probably give cause for a revision.

In the calculation of loss of virgin glass upon landfilling and incineration it is assumed that half of the glass used is recycled cullet (where loss of utility value is included in reprocessing) and the loss of utility value thus is only half of the 10%. Thus, a loss of primary resources of 95% of virgin glass is included in landfilling and incineration.

For incineration and landfilling 1 kg per 1 kg glass is landfilled (incl. 5% loss of utility value). Incineration may allow for recycling of slag – here 60% is included /40/. Finally, a minor amount of energy for heating glass from ambient temperature to slag temperature has been included. However, this has not been included here, as it accounts for a maximum of 0.2 MJ/kg, thereby disappearing in the decimals.

3.2.3 Sensitivity assessment of indicator values for glass

Data used for manufacture, washing and remelting of glass is relatively well verified in connection with a life-cycle survey for beverages packaging. However, the picture may change, when the electricity data used is updated to the most recent figures for the LCA project on electricity generation. For some parameters changes of 10-20 % may arise compared to figures used.

3.3 Aluminium

3.3.1 Quantities and statistics

In the ISAG, aluminium is included in other metals. The total metal fraction consists primarily of iron and steel. A statement of quantities of aluminium disposed of and ways of disposal must therefore be based on other data.

Imports and exports of scrap aluminium and production of secondary aluminium appear from trade statistics from Statistics Denmark. For individual fractions of scrap aluminium, however, aluminium only accounts for a minor part of scrap, and total quantities led to recycling therefore can only be estimated on the basis of more detailed knowledge of scrap composition. It is, however, estimated to be possible to get an approximate figure for quantities led to recycling from statistics and data on composition from the most recent mass-flow analysis for aluminium /1/.

Quantities led to incineration and landfilling cannot be estimated directly from existing statistics and must therefore be based on more detailed, individual analyses. The most recent mass-flow analysis for aluminium covers data for 1994. The mass-flow analysis also covers non-metallic applications, and in the present analysis it has been necessary to extract data concerning metallic applications.

According to the mass-flow analysis the following quantities were treated in 1994:

- 7,000-12,700 tonnes of metallic aluminium for waste incineration (average: 9,800 tonnes).

- 2,800-7,200 tonnes of metallic aluminium for landfilling (average: 5,000 tonnes). Of this, 2,000-5,500 tonnes were disposed of through domestic waste and bulky waste, whereas the remaining part consisted of production waste and shredder waste.

- 27,100-34,600 tonnes for recycling (average: 30,900 tonnes).

Quantities of domestic waste and bulky waste led to incineration are estimated to have increased at the expense of quantities led to landfilling in the period since 1994.

The element most relevant for use as a measurement for recycling will be the collection of aluminium, whether the materials collected are reprocessed in Denmark or exported.

In connection with the mass-flow analysis, aluminium alloys have been converted into pure Al on the basis of an average content of aluminium in the alloys. For calculation of indicators, however, it will be most expedient to calculate the total weight of aluminium alloys as aluminium, partly to simplify calculations, and partly to also incorporate alloy elements in the calculation (that for reasons of simplicity are considered to correspond to aluminium).

Quantities led to recycling can be calculated annually as follows, based on trade statistics from Statistics Denmark:
Quantities collected = production of sec. Al in DK + exports of scrap Al ÷ imports of scrap Al. Contents of aluminium (incl. alloy elements) in the different scrap fractions have been estimated on the basis of the mass-flow analysis.

Table 3.1. Metallic aluminium in Denmark in 1994 /1/

Code number	Designation	Imports Al%	Tonnes/year	Tonnes Al/year	Exports Al%	Tonnes/year	Tonnes Al/year	Net Tonnes Al/year
7602.00.11	Aluminium waste: Turnings, shavings, chips, milling waste, sawdust and filings; waste of coloured, coated or bonded sheets and foil	100	6,941	6941	100	4,245	4245	-2696
7602.00.19	Other aluminium waste	30	4,252	1275.6	90	5,919	5327.1	4051.5
7602.00.90	Aluminium scrap	90	13,132	11818.8	90	21,048	18943.2	7124.4
7601.20.90	Production of secondary Al							21,250
	Total							29,730

This method will often underestimate actual quantities, as aluminium included in mixed scrap, which is entered in other code numbers, is not included.

Calculated in this way collected quantities can be estimated as follows for each year:

1991 30,752 tonnes
1994 29,730 tonnes
(the mass-flow analysis states an average of 30,900 tonnes Al)
1996 39,271 tonnes
1998 40,896 tonnes

3.3.2 LCA processes and data sources

Data for production of aluminium is found in environmental profiles for aluminium /16/. This data derives from the European aluminium industry supplemented with the EDIP project's data for electricity consumption for production of aluminium.

For recycling of aluminium the EDIP project's data has been used. However, a conversion has been made, as the EDIP project assumes use of scrap aluminium with an aluminium content of 93%. Together with loss upon oxidation of aluminium in the remelting process of around 5-6% this means a total loss during collection and remelting of aluminium of 13%.

As this statement uses pure aluminium it is assumed that it is only relevant to count with a loss of around 5%, so 1 kg of scrap aluminium turns into 0.95 kg recycled aluminium, which is assumed to be the case for Danish conditions according to the mass-flow analysis for aluminium /1/.

Upon incineration of aluminium, 1.9 kg aluminium oxide will be generated for each kilo of incinerated aluminium. Aluminium oxide will be bound in slag or filter dust. Therefore, as a result of both incineration of aluminium and the loss occurring in remelting 1.9 times as much waste for landfilling as the lost aluminium has been used in the calculation. Some slag is recycled, whereas filter dust is normally landfilled: around 60% according to the ISAG for 1999 /40/.

Energy recovery upon incineration of aluminium has been set at a calorific value of around 31 MJ per kg reduced by 30%, which gives a credit of 21.7 MJ/kg converted into a credit of 879 g coal per kg aluminium and around 12% saved landfilling of coal waste in connection with extraction. Coal slag is recycled 100% today /23/.

In the EDIP it is assumed that aluminium led to incineration plants typically is of a thickness that allows for burning. Other surveys show that, for example, foil sleeves normally do not burn, but are found unburned in the slag. Figure 5.3 in the main report shows that the effect of changing the percentage burned to 50%, for example, will be marginal. However this assumption should be reassessed in connection with an indicator calculation for the entire waste management field. Aluminium of a larger thickness that cannot burn 100% is assumed to be collected and remelted.

Aluminium is recycled as aluminium, and in the revised EDIP project no loss of utility value has been included for aluminium. Therefore, no loss of utility value has been included for primary aluminium when it is disposed of by landfilling or incineration.

3.3.3 Data quality and sensitivity

There is a significant difference in the resource evaluation, depending on whether aluminium is recycled or landfilled. Therefore, good LCA data for production and recycling of aluminium is decisive. Especially the electricity scenarios used are important, and the EDIP data dates from 1992. Most recent electricity data for Danish electricity generation has changed by 10-20% in some areas, and an update of the data basis for the electricity scenario used will change aluminium indicators correspondingly. However, in general aluminium data used is estimated to be of good quality, and it is based on Danish conditions.

3.4 Weighting and normalisation factors

3.4.1 Resources

Normalisation and weighting factors for a number of raw materials have been estimated in the EDIP project and are covered by the database. For many raw materials no normalisation and weighting factors are available in the EDIP database. To be able to include these raw materials factors have been estimated here according to methods that are comparable with the methods of calculation of normalisation and weighting factors in the EDIP. Factors calculated appear from the following table.

Table 3.2. Supplementing normalisation and weighting references

	Weighting factor 1/year	Normalisation reference kg/pers./year
Limestone 1)	0.002	598
Uranium ore 2)	0.015	0.007
Sulphur 3)	0.036	9.6
Quartz sand 4)	0.005	36
Gravel and sand 5)	0.005	5.6 (m^3/pers./year)

1) In the EDIP database there are no normalisation and weighting factors for lime. There is no statement of global consumption of lime, and a large part of the consumption of limestone in statements from the US Geological Survey has been entered under stone. The normalisation factor for lime therefore will be based on the local (national) consumption of lime. Total extraction of lime and chalk in Denmark in 1990 amounted to 2,924,000 m^3 /29/. Consumption of lime with finished goods for 1995 has been stated at 3,052,000 tonnes /6/. With offset in this statement, consumption of lime can be calculated at 598 kg/person. A large part is used in the form of cement.

No statement is available of global or regional reserves of lime, but resources are very large, so the weighting factor has been set roughly at 0.002 – corresponding to a supply perspective of 500 years (see also statements in /6/).

2) In the EDIP database there are no normalisation and weighting factors for uranium. Factors have therefore been fixed here on the basis of a stated consumption (mining) of 34,583 tonnes in 1992 and stated reserves of 2,255,000 tonnes /26/.

3) Global extraction of sulphur in 1994 has been stated by the USGS at 51 million tonnes /36/. Global reserves have been stated at 1,400 million tonnes, corresponding to a supply perspective of around 27 years. Global resources have been stated at 5 billion tonnes, but there are very large alternative resources, for example at least 500 billion tonnes in coal, oil etc. and very large resources in gypsum and anhydrite.

4) Extraction of quartz sand in 1990 amounted to 186,000 tonnes. It was mainly used as foundry sand, sand blasting and concrete sand. No total statement of Danish resources of quartz sand is available. According to statements from the USGS (1999) global resources of quartz sand are very large, and from a resource point of view it is mainly a question of increased transportation of raw materials. To get a measurement that can be used to indicate whether consumption of quartz sand is of significant resource-related impact, the supply perspective is estimated at roughly 200 years.

5) In the EDIP database there are no normalisation and weighting factors for sand and gravel. In Danish life-cycle analyses under the EDIP method the use of these raw materials has been disregarded. Total Danish consumption of gravel and sand in 1990 amounted to 22.4 million m^3 from land and 6.2 million m^3 from the seabed /29/, corresponding to a total average per person of around 5.6 m^3.

At present no statement of total Danish raw material resources on land is available /21/. Statements of raw material resources are carried out at the regional level. The Danish Forest and Nature Agency assesses that in a few years a total statement and assessment of raw material resources will be made. Resources of sand, stone and gravel in the seabed were stated in 1998 at around 4,500 million m^3, corresponding to around 725 times the present annual extraction from the seabed of 6.2 million m^3 or 150 times the total annual extraction of sand and gravel /17/. However, there are large variations in the composition of resources, and gravel and pebble gravel/stone are stated to be a limited resource.

For the other raw materials the supply perspective is calculated in the EDIP (and used for the weighting) on the basis of global ”reserves” and not total estimated global resources. Reserves will typically be around 10-20% of estimated total resources. Resource statements for the Danish marine area cover both ”probable resources” and ”speculative resources” and cover thus a considerably larger part of resources than the quantity referred to as ”reserves”.

However, for sand and gravel there do generally not seem to be supply problems at present, and to get a measurement that can be used to indicate whether consumption of sand and gravel is of significant resource-related impact, the supply perspective is estimated roughly at 200 years.

3.4.2 Energy

Energy consumption in Denmark in 1995-1999 amounted to a total of 840 PJ (corrected for climate and for fluctuations due to exports of energy). As for waste, an average has been chosen for recent years, even if values have only fluctuated little over the years. This gives a consumption of 160 GJ per person in Denmark, which corresponds to the calorific value of around 3800 litres of oil /9/. The normalisation factor is 0.00625.

It is estimated that direct comparison across the three indicators is not relevant, and therefore it has been decided not to use a weighting factor for energy.

3.4.3 Landfill requirement

In the normalisation of waste quantities in the EDIP, waste output is normalised in relation to waste generated, analysed into four types: radioactive waste, hazardous waste, bulk waste, and ash and slag. Radioactive waste is normalised in relation to the average for Europe, whereas the other three are normalised in relation to waste generation per capita in Denmark in 1992.

In the waste indicator project it has been decided instead to normalise in relation to waste quantities landfilled. This choice has been made based on the consideration that waste led to landfilling constitutes the actual waste problem. Waste incinerated is converted into other types of pollution and slag for landfilling.

In setting up normalisation values, an average of waste landfilled in the period 1995 - 1998 has been used, which is quantities landfilled in the last four years. The average for the period has been chosen, as there are large fluctuations over the years, and the four annual values are close to the average, of 2,116,000 tonnes. Population in Denmark in the same period was around 5.25 million /40/. This gives a normalisation value for waste landfilled of 403 kg per person-equivalent.

It is estimated that direct comparison across the three indicators is not relevant, and therefore it has been decided not to use a weighting factor for landfill requirement.

3.5 Incineration of waste in Denmark

In setting up the three LCA indicators for resources, energy and landfilling upon landfilling of waste paper account is taken of the fact that a corresponding amount of virgin paper must be manufactured, and that waste paper is landfilled 100%.

Paper to be manufactured to substitute paper disposed of is based on a mix of 50% primary paper and cardboard and 50% recycled paper. The proportion of paper for recycling has been set relatively high, but considering that half of total consumption of paper and cardboard for recycling has been separated, it is not unreasonable to assume that the qualities remaining are the poorest ones.

For the share of recycled paper, the resource loss should only be calculated with the utility value of the recycled fibres, i.e. 80% according to the EDIP, as the paper in question is mixed. This means that for paper landfilled or incinerated, a resource loss of primary paper is included of 50% + 0.8 times 50%, i.e. 90% resource loss.

Data for paper manufacture for primary paper is an average for different types of primary paper processes that the Institute for Product Development has supplied in connection with the project on the environmental impact of the family. The average has been weighted in relation to the Danish consumption in 1998 /39/ to the extent that is has been possible to find data for manufacture of the different paper types.

Upon landfilling only the actual landfilling has been included – and transportation of paper as well as establishment, operation and maintenance of the landfill site are disregarded.

3.5.1 Incineration and generation of heat

In the statistics on energy-generating plants /33/ for 1999, 29,105 TJ gross energy from waste for incineration is entered in 1999. According to waste statistics for 1999, around 2,700 tonnes of waste was led to incineration (for example incineration of sludge).

This gives a calorific value of 10.8 MJ per kilo waste. Incineration of different plastic types gives more energy, whereas non-burnable material and wet organic waste reduces the average.

Some heat from waste is cooled off in cooling towers during summer – this means that energy is not recovered fully for district heating, and some heat is utilised internally for the operation of the waste treatment plant, for example for drying waste. According to the statistics on energy-generating plants, waste incineration plants supply a total of 20,825 TJ heat and 5,150 TJ power. For the generation of this energy, waste is used with a calorific value of 29,105 TJ and auxiliary fuel of a total of 4,934 TJ. This gives a total efficiency in waste incineration of 76%, and the result is 8.2 MJ/kg waste delivered to the district heating network.

3.5.2 Extension of system boundary in analysis of waste energy

However, the above only applies to a consideration of waste treatment in a closed system. If the system is extended to cover the entire power and heat supply of Denmark, it will also be necessary to try to include resulting changes to the remaining system from waste incineration. Based on the statistics on energy-generating plants it has been sought to identify district heating systems where heat from waste is recovered.

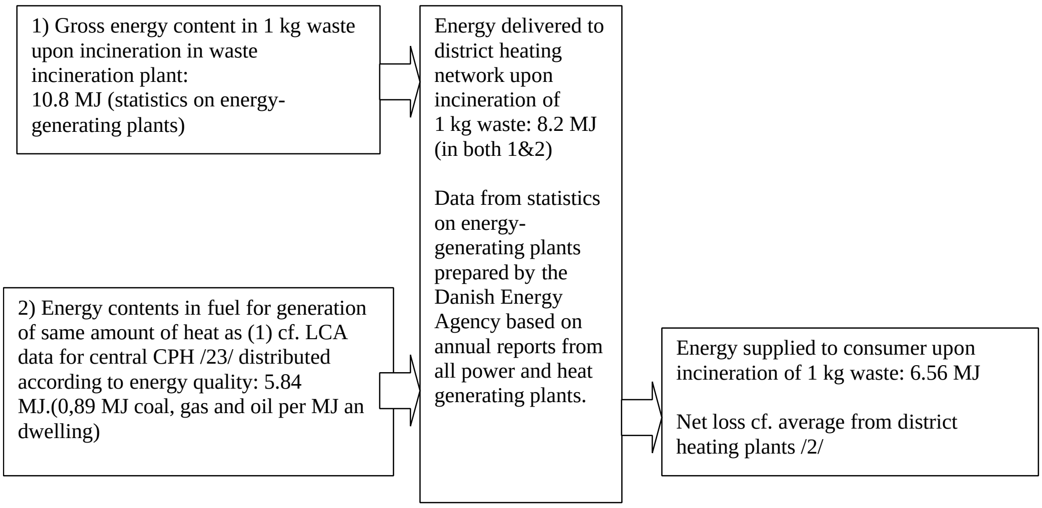
The statistics on energy-generating plants for 1999 contain information on fuel consumption analysed by types and generation of power and heat for each individual plant. Statistics also contain information on affiliation of the plants to the district heating network.

An analysis of recovery of energy from waste shows that around 67% of waste is incinerated in plants co-generating power and heat. The efficiency for power fluctuates between 15 and 25% of energy fired. In this case waste will substitute other power and heat generation, typically using fossil fuels such as coal, natural gas, and oil. Waste incineration substitutes the base load of power plants and thus typically substitutes coal-fired power and heat plants.

33% of waste is incinerated in waste incineration plants that supply heat to district heating networks only. A small number of these networks is not affiliated to other power and heat generating plants, and the heat generated from waste for these networks (about 7 %) substitutes other fuel types 100%, typically natural gas or oil, as the plants in question are small.

The remaining 26% of total energy from waste is delivered to district heating networks to which power generating plants are also affiliated. This 26% includes the incineration plant of Vestforbrænding (in the western part of Copenhagen), as heat from incineration in this plant limits the possibilities of exploiting more waste heat from the many other power and heat plants in the area.

Figure 3.1. Energy substitution from waste incineration



The figure shows the result of incinerating 1 kg of waste (1) and what is saved from co-generating heat and power (2), cf. energy generation figures from the most recent LCA review of power and heat generation in Denmark /23/.

3.5.3 Conclusion

In a system only covering waste incineration, most heat from waste incineration is recovered for energy generation – either for power and heat or only heat generation. But if the system is extended to cover the entire power and heat generation, around 26% of heat from waste will substitute recovery of waste heat from cogeneration, so that it leads to lower rate of exploitation at the central power and heat plants.

This means that energy recovery of waste, on average 8.2 MJ/kg waste, must be reduced to 5.84 MJ to compensate for the 26% of waste that competes directly with combined power and heat generation. It costs 5.84 MJ to generate district heating in connection with power and heating plants /23/. This means that the average energy recovery of 8.2 MJ upon incineration of 1 kg waste in Denmark is reduced to an average of 7.6 MJ. This means that around 70% of the calorific value of waste is recovered in the present system. Other surveys reach a figure of around 75%, but they do not include a ”system loss” for increased wastage from power and heat plants.

This figure is only slightly lower than a calculation carried out by the Danish Energy Authority on the basis of the statistics on energy-generating plants for

1998, which has been used in an LCA of packaging. The Danish Energy Authority assumes an average recovery of 75% of energy generated, but does not take the above ”extended system loss” into account.

Below, the actual energy recovery for the different materials is calculated based on materials’ calorific value that must be reduced by 30%, when the figure is to represent an average for energy benefits from incineration of waste in Denmark. Calorific values of materials appear, for example, from /15/. If it is assumed that cardboard accounts for one third of total quantities of paper and cardboard for incineration it means that an energy recovery must be included of 15 MJ - 30% = 10.5 MJ/kg, corresponding to a credit of coal consumption of 420 g. Furthermore, around 12% of landfilling of coal waste saved in connection with extraction is included. Today, slag from coal combustion is recycled 100%.

3.6 Use of slag for construction purposes

If the use of slag for construction purposes is to be included in the calculation of the indicator for resources, it is necessary to clarify which raw materials are actually substituted through the use of slag, and to set up normalisation and weighting factors for these raw materials.

In 1998, 80% of 551,000 tonnes of slag generated was used for construction purposes. The use of slag depends on requirements for the structure in which it is used. On bicycle paths and parking grounds, slag can be used as sub-base, thus substituting stable gravel. For roads, slag is normally not used as sub-base, but as pitching and friction filler. Materials substituted in this case will typically be sand or soil.

In the new Statutory Order on residues and soil for building and construction purposes, limits to the use of slag have been set up, depending on the contents of problematic substances in slag /34/. After 1 January 2001 slag in the most contaminated category 3, (where most slag is expected to belong), can only be used for roads with tight paving and discharge of surface water, paths and conduits with solid paving as well as foundations and floors below buildings (where soil must not cause indoor climate problems).

If the resource-related benefit from using slag is to be included in the calculated indicators, it will be necessary to set up normalisation and weighting factors for the materials substituted by slag. Without these, in the calculation of indicators for resources it would be of no importance whether or not slag is recycled. In the calculation of the indicator for landfill requirement it will always be important whether slag is recycled or landfilled.

In statistics on raw material extraction in Denmark, sand, gravel and stone are listed together, and with data available on resources of the different fractions within this group it will not be expedient to make a further division. Total Danish extraction of gravel and sand in 1990 amounted to 22.4 million m^3 from land and 6.2 million m^3 from the seabed /29/, corresponding to a total average per person of around 5.6 m^3. If an average density of 2 tonnes/m^3 is used, this corresponds to 11.2 tonnes.

At present no statement of total Danish raw material resources on land is available /21/. Statements of raw material resources are carried out at regional level. The Danish Forest and Nature Agency assesses that in a few years a total statement and assessment of raw material resources will be made.

Resources of sand, stone and gravel in the seabed was stated in 1998 at around 4,500 million m^3, corresponding to around 725 times the present annual extraction from the seabed of 6.2 million m^3 or 150 times the total annual extraction of sand and gravel /17/. However, there are large variations in the composition of resources, and gravel and pebble gravel/stone are stated to be a limited resource.
For the other raw materials the supply perspective is calculated in the EDIP (and used for the weighting) on the basis of global ”reserves” and not total estimated global resources. Reserves will typically be around 10-20% of estimated total resources. Resource statements for the Danish marine area cover both ”probable resources” and ”speculative resources” and thus cover a considerably larger part of resources than the amount referred to as ”reserves”.

As mentioned, no total statement of resources on land is available, but for sand and gravel there do not generally seem to be supply problems at present, and to get a measurement that can be used to indicate whether consumption of sand and gravel is of significant resource-related impact, the supply perspective is estimated roughly at 200 years.

To survey the resource-related impact of recycling slag, a brief calculation is made below for recycling of 500,000 tonnes of slag.

The following assumptions have been made:

- The 500,000 tonnes of slag substitutes 500,000 tonnes of sand and gravel
- Transportation of slag for use in construction corresponds to transportation of slag for landfilling
- The normalisation factor for sand and gravel is 11.2 tonnes/person/year
- The weighting factor for sand and gravel is 0.005 (corresponding to a supply perspective of 200 years)

With these assumptions, resource-related savings from recycling of 500,000 tonnes of slag – excluding extraction and transportation of sand and gravel – amount to 223 PR.

In comparison, total resource consumption associated with disposal of aluminium and manufacture of substitute materials is calculated at 23,000 PR. Thus, with the above calculation, resource-related savings from recycling of slag are modest. Uncertainties in relation to supply perspective thus do not have a significant impact on global results.

3.6.1 Conclusion

In the calculations, recycling of slag has been included, as it has a significant impact on the landfill indicator. Resource savings from recycling slag for substitution of sand and gravel, by contrast, have not been included as, cf. the above, it has no significant impact in relation to other resource consumption.

Thus, slag is primarily recycled to reduce landfill requirements – and not because it solves a significant resource problem.