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Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks

Main Report

Ministry of Environment and Energy, Denmark
Danish Environmental Protection Agency

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Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks

Main Report

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Preface

The study

This report is the main report in a series of 8 reports from a life cycle assessment (LCA) comparing the potential environmental impacts associated with different existing or alternative packaging systems for beer and carbonated soft drinks that are filled and sold in Denmark.

Main report

Main report: Goal and scope definition, including description and discussions on methodology. Summary of the LCA of the different packaging systems. Comparisons of the different packaging systems. Comparison of the previous and the updated study.

Individual systems

Technical report 1: Refillable glass bottles: including description of the system, data, inventory analysis, impact assessment, and interpretation.

Technical report 2: Disposable glass bottles: including description of the system, data, inventory analysis, impact assessment, and interpretation.

Technical report 3: Aluminium cans: including description of the system, data, inventory analysis, impact assessment, and interpretation.

Technical report 4: Steel cans: including description of the system, data, inventory analysis, impact assessment, and interpretation.

Technical report 5: Refillable PET bottles: including description of the system, data, inventory analysis, impact assessment, and interpretation.

Technical report 6: Disposable PET bottles: including description of the system, data, inventory analysis, impact assessment, and interpretation.

Energy and transports

Technical report 7: Energy and transport scenarios, including energy and transport data, sensitivity analysis and data quality assessment.

Commissioner and practitioner

The study was financed by the Danish Environmental Protection Agency (DEPA). It was performed by Chalmers Industriteknik (CIT), Göteborg, Sweden and Institute for Product Development (IPU), Lyngby, Denmark.

Critical review

The project as a whole, including this report and the seven Technical reports, has been peer reviewed following the procedure outlined in section 2.15.

Project framework

This report was produced during the period December 1997 to May 1998. The entire project was scheduled for May 1997 to May 1998.

Adherence to ISO

We adhere to the requirements of the standard ISO 14040 and the draft standard ISO FDIS 14041. Several of the requirements and recommendations presented in the ISO documents need to be interpreted. We present our interpretations where applicable.

Sammendrag

Sammenligning

Denne rapport præsenterer en livscyklusvurdering hvor potentielle miljøeffekter fra forskellige eksisterende og alternative emballagesystemer til øl og læskedrikke, påfyldt og solgt i Danmark, sammenlignes. Miljøvurderingen sammenligner retur- og engangsglasflasker og PET flasker samt aluminiums- og ståldåser. Udelukkende emballager af ens størrelse sammenlignes.

Opdatering

Denne undersøgelse er en opdatering af en tidligere undersøgelse udført i perioden 1992 til 1996. De vigtigste ændringer i forhold til den tidligere undersøgelse er at

- datagrundlaget er forbedret og opdateret
- der tages højde for forhold som har ændret sig siden den tidligere undersøgelse
- De internationale standarder ISO 14040 og ISO FDIS 14041 er overholdt og
- de seneste metodemæssige resultater i det danske projekt Udvikling af Miljøvenlige industriprodukter (UMIP) er anvendt.

Formål

Formålet med at udføre denne opdaterede miljøvurdering er at forbedre grundlaget for mulige beslutninger vedr. valg af emballagesystemer til øl og læskedrikke som sælges i Danmark.

Projektparter

Miljøvurderingen er udført af Chalmers Industriteknik (CIT), Göteborg, Sverige og Institute for Product Development (IPU), Lyngby, Danmark. Resultaterne er reviewed af et panel af fem uafhængige LCA-eksperter (se afsnit 2.15).

Afgrænsning

LCA'en inkluderer ikke kun emballage systemerne men også distribution af øl og læskedrikke. Systemgrænserne er udvidet til at omhandle dele af andre systemer som påvirkes af emballagernes genbrugssystemer eller af affaldsforbrændingen med genvinding af energi (se afsnit 2.5).

Marginal data

De data som bør anvendes i denne rapport repræsenterer de teknologier, som i praksis påvirkes af valg af emballage system. Hvad angår markeder, hvor valget af emballage system vil have en marginal indflydelse, f.eks. elektricitets- og materialemarkedet, afspejler data den langsigtede marginale teknologi, som vurderes at være den mest relevante for denne rapport. Dette metodiske valg er særlig betydende for miljøpåvirkningerne fra elektricitetsproduktion.

Antagelser

De vigtigste antagelser beskrives og diskuteres i afsnit 2.7. En af de vigtige antagelser er, at forbrugerens adfærd ikke påvirkes af valget mellem forskellig slags emballage, hvis størrelsen af emballagen er ens.

Vi antager også at de undersøgte emballager vil fungere i retursystem, som det der p.t. er i Danmark for returflasker. Indsamling af genbrugsflasker vurderes at være 98,5%. Indsamling af engangsflasker og dåser med henblik på genvinding af materialer antages at være 90%. Der er udført følsomhedsanalyser baseret på genbrugsrater.

Indsamlede aluminiumsdåser antages at blive genanvendt til nye dåser, hvor det genvundne materiale erstatter primære råmaterialer. Genvundet glas og stål antages at erstatte primære råmaterialer i andre produktsystemer. Genvundet PET antages at erstatte 50% af primære råmaterialer og 50% genvundet PET fra andre systemer.

I det grundlæggende scenario, antages langsigtet marginal teknologi for elektricitetsproduktion at være kulbaseret. Andre energiscenarier indgik i følsomhedsvurderingen.

Effekttyper

Denne rapport anvender UMIP-metoden og inkluderer effekttyperne drivshuseffekt, stratosfærisk ozonnedbrydning, fotokemisk ozondannelse, forsuring, næringssaltsbelastning, human toksicitet (forårsaget af påvirkning via luft, vand og jord), økotoksicitet (akut og kronisk toksicitet i vand og kronisk tokcitet i jord). Ligeledes er ressourceforbrug og affaldsproduktion inkluderet. UMIP-metoden inkluderer ikke påvirkninger relateret til arealanvendelse, støj, lugt, stråling, påvirkning fra udledning af BOD og COD og henkastning af affald i naturen. Arbejdsmiljø og sundhedsmæssige konsekvenser af brug og misbrug af emballagen er ikke medtaget i denne rapport. Dette betyder bl.a. at de sundhedsmæssige konsekvenser fra kemiske påvirkninger fra emballagen til drikkevaren ikke er medtaget i denne undersøgelse.

Hvad angår human toksicitet og økotoksicitet fandt vi ingen signifikante forskelle i systemerne. Dette betyder ikke at de forskellige systemer giver ensartede toksicitetspåvirkninger, men blot at usikkerhederne er meget store. I undersøgelsen er ikke påvist udledninger, som bidrager signifikant til stratosfærisk ozonlagsnedbrydning, se i øvrigt afsnit 2.11.

Usikkerhedsvurdering

Usikkerheden i en bred undersøgelse som den aktuelle kan være stor. Betydningen af forskellige usikkerheder gennemgås i følsomhedsanalysen (afsnittene 10.3, 11.3, 12.4, 13.3 and 14.3) og i vurderingen af datakvalitet og datamangler (se f.eks. afsnittene 5.3-5.4 i de tekniske rapporter 1-6). Vi har bedømt at de væsentlige usikkerheder relaterer sig til:

- marginal elektricitets produktion,
- markedet for genanvendte materialer,
- genbrugsrater og
- data for transport.

Rangorden

Hvad angår effektyperne drivhuseffekt, forsuring, fotokemisk ozondannelse og næringssaltsbelastning, præsenteres den indbyrdes prioritering af effekttyperne i tabellerne S. 1 og S. 2. Denne rangorden afspejler de signifikante forskelle på systemerne og tager hensyn til den tidligere nævnte usikkerhedsvurdering. Imidlertid, skal det pointeres, at vurderingen og rangordenen er baseret på danske forhold. Forskellene mellem emballage til øl og til læskedrikke er lille. Dette indebærer at konklusionen for 33 cl emballage til øl også gælder for 33 cl emballage til læskedrikke.

33 cl packagings

Energiforbrug, drivhuseffekt, forsuring, næringssaltsbelastning og fotokemisk ozondannelse er signifikant lavere for retur-glasflasker end for engangsflasker med samme volumen, se tabel S.1. Årsagen hertil er, at omsmeltning af glas kræver mere brændsel og el end vask og påfyldning af retur-glasflasker.

Tabel S.1
Miljømæssige rangorden af eksisterende og alternative systemer med 33 cl emballage til øl og læskedrikke, som påfyldes og sælges i Danmark.

Miljøpåvirkerne	Retur-flasker af glas	Engangs-flasker af glas	Aluminiums-dåser	Stål-dåser
Drivshuseffekt	1-2	2-4	1-3	3-4
Photokemisk ozondannelse	1-2	2-4	1-3	3-4
Forsuring	1-2	3-4	1-2	3-4
Næringssaltsbelastning	1-2	3-4	1-2	3-4

Retur-glasflasker vs. aluminiumsdåser

Forskellene i drivshuseffekt, fotokemisk ozondannelse, forsuring og næringssaltbelastning mellem retur-glasflasker og aluminiumsdåser (33 cl) er ikke signifikante. Den vigtigste årsag hertil er de store usikkerheder i miljøpåvirkningerne fra marginal el-produktion (se også afsnit 10.4).

Forbruget af el er betydelig lavere for retur-glasflasker end for aluminiumsdåser. Forbruget af fossile brændsler til procesenergi og til transport er lavere for aluminiumsdåser, men hvis marginal el-produktion baseres på fossile brændsler, vil det totale forbrug af fossile brændsler være signifikant højere for aluminiumsdåser end for retur-glasflasker.

Aluminium vs. stål

Aluminiumsdåser er ud fra de givne forudsætninger miljømæssigt bedre end ståldåser med aluminiumslåg, så længe aluminiumslåget ikke genvindes. Forskellene mellem miljøpåvirkningerne fra en aluminiumsdåse og en ståldåse er relativt små - ca. 20% - men forskellene er signifikante hvis retur raten ligger omkring 90%, og det genvundne aluminium og stål erstatter 100% af primære råmaterialer. Denne konklusion er holdbar for drivhuseffekt, forsuring, næringssaltsbelastning og fotokemisk ozondannelse. Forbruget af fossile brændsler er signifikant lavere for aluminiumsdåsen i forhold til ståldåsen. Forholdene gør sig gældende for så vel 50 cl og 33 cl dåser, som for dåser til øl og læskedrikke. Hovedårsagen til de nævnte forskelle er at behovet for primær aluminium er højere i ståldåsesystemet, fordi aluminium går tabt ved omsmeltning af ståldåsen, og at ståldåsesystemet herudover kræver produktion af stål (se afsnit 11.4).

50 cl læskedrik-emballage

Energiforbruget, drivshuseffekt, forsuring, næringssaltbelastning og fotokemisk ozondannelse er signifikant lavere for retur-PET-flasker end for engangs PET-flasker af samme størrelse, se tabel 15.2. Denne erkendelse gælder for såvel 150 cl flasker som for 50 cl flasker. Grunden er, at genvinding af PET anvender mere brændsel og el end vask og påfyldning af returflasker.

Tabel S.2

Miljømæssig rangorden af eksisterende og alternative systemer med 50 cl emballage til øl og læskedrikke påfyldt og solgt i Danmark

Miljøpåvirkninger	Retur-PET-flasker	Engangs PET-flasker	Aluminiums-dåser	Ståldåser
Drivhuseffekt	1	2-4	2-3	3-4
Fotokemisk ozondannelse	1-3	4	1-2	2-3
Forsuring	1-2	4	1-2	3
Næringssaltsbelastning	1-2	2-4	1-3	3-4

Retur-PET vs aluminium

Vores resultater indikerer at potentielle miljøeffekter for drivshuseffekt, forsuring og næringssaltsbelastning er væsentlige lavere for 50 cl retur-PET-flasken end for andre 50 cl læskedrik-emballager, incl. aluminiumsdåsen. Imidlertid er der store usikkerheder forbundet med resultaterne. Som følge af disse usikkherheder, betragter vi ikke forskellene mellem retur-PET-flasken og aluminiumsdåsen, med hensyn til forsuring, næringssaltsbelastning og fotokemisk ozondannelse som signifikante. Kun forskellen i drivhuseffekt er signifikant (se også afsnit 13.4).

Forbruget af el er signifikant lavere for 50 cl retur-PET-flasken i forhold til 50 cl aluminiumsdåsen. Hvis marginal el-produktion er baseret på fossile brændsler, er det totale forbrug af fossile brændsler signifikant lavere for retur-PET-flasken end for aluminiumsdåsen.

Miljøforbedringer i emballagesystemer

Mange miljømæssige forbedringer kan indføres i systemerne. Det var ikke dette projekts formål af identificere miljømæssige forbedringer. Imidlertid er to vigtige forbedringspotentialer identificeret. Resultatet af LCA'en for ståldåsen viser en miljømæssig gevinst hvis aluminiumslåget på ståldåsen omsmeltes til sekundær aluminium istedet for at gå tabt ved omsmeltning af ståldåsen. Resultatet for LCA'en af returflasker tyder på at der kan opnås en signifikant miljømæssig gevinst ved forbedret energiudnyttelse ved vask af flaskerne.

Forbedringer af LCA'en

Miljøvurderingen i dette projekt kan forbedres. Væsentlige forbedringer inkluderer en tilbundsgående analyse af markedet for genbrugsmaterialer, af el-markedet samt tilvejebringelse af bedre data for emissioner af Sr og Hg (se også afsnit 15.4).

Summary

A comparison

This report presents a life cycle assessment (LCA) comparing the potential environmental impacts associated with different existing or alternative packaging systems for beer and carbonated soft drinks that are filled and sold in Denmark. The comparisons involve refillable and disposable glass and PET bottles, as well as aluminium and steel cans. Only packagings of the same size are compared, since the consumption of beverage is likely to be affected by the container size.

An update

The study is an update of a previous study performed in the period 1992 to 1996. The most important changes compared to the previous study are:

- data are improved and updated,
- conditions which have changed since the previous study are taken into account,
- the international standards ISO 14040 and ISO FDIS 14041 are used, and
- the most recent developments within the Danish project on Environmental Design of Industrial Products (EDIP) are taken into account.

Purpose

The purpose of this updated comparison is to improve the basis for possible decision-making on packaging systems for beer and carbonated soft drinks to be filled and sold in Denmark.

Organization

The LCA was carried through by Chalmers Industriteknik (CIT), Göteborg, Sweden and Institute for Product Development (IPU), Lyngby, Denmark. The study was peer reviewed by a panel of five independent LCA experts (see section 2.15).

Systems boundaries

The LCA includes not only the packaging systems but also the distribution of beverage. System boundaries are also expanded to include parts of other systems that are affected by recycling in the packaging system or by waste incineration with energy recovery (see section 2.5).

Marginal data

The ideal data to use in this study represents the technologies actually affected by a decision on the packaging system. For markets where the decision will have a marginal impact - *e.g.*, electricity and bulk material markets - data reflecting the long-term marginal technology were judged to be the most relevant for the purpose of this study (section 2.9). This methodological choice is particularly important for the environmental impacts of electricity production.

Assumptions

The key assumptions are described and discussed in section 2.7. One of the important assumptions made is that consumer behaviour is not affected by the choice between packagings of similar size (section 2.7.1). We also assume that all the analysed systems will operate under a return scheme. The collection rate for refillable glass bottles is assumed to be 98.5%. Of the used disposable bottles and cans, 90% is assumed to be collected for recycling of the materials (section 2.7.2). Sensitivity analyses were made based on other collection rates (see section 2.13.2).

In the base case scenario, the long-term marginal technology for electricity production is assumed to be coal condensing power. Other energy scenarios were used in the sensitivity analysis (see section 2.7.3 and Technical report 7).

The collected aluminium cans are assumed to be recycled into new cans, replacing virgin raw materials. Recycled glass and steel are assumed to replace virgin raw materials in other product systems. Recycled PET is assumed to displace 50% virgin raw materials and 50% recycled PET from other systems. See also section 2.7.5.

Impact categories

The impact assessment method used in this study is the EDIP method. It takes into account potential global warming, stratospheric ozone depletion, acidification, nutrient enrichment, photochemical ozone formation, human toxicity (caused by exposure via air, water and soil) and ecotoxicity (acute and chronic toxicity in water, and chronic terrestrial toxicity). It also takes resource depletion and generation of waste into account. The EDIP method does not take into account land-use related impacts, noise, odour, radiation impacts, impacts of BOD and COD emissions, and littering in nature. Work environment and health impacts from use and misuse of the packaging are not included in this particular study.

For human toxicity and ecotoxicity impacts, we found no significant differences between the systems. This is not because the different systems have similar toxicity impacts, but because the uncertainties are very large. No emissions contributing significantly to stratospheric ozone depletion were recorded in this study. For further information, see section 2.11.

Uncertainties

Large uncertainties are involved in a broad systems analysis such as this. The importance of various uncertainties is addressed in sensitivity analyses (sections 10.3, 11.3, 12.4, 13.3 and 14.3) and in assessments of data quality and data gaps (*e.g.*, sections 5.3-5.4 in Technical reports 1-6). We estimate that the most important uncertainties concern:

- the marginal electricity production,
- the market for recycled materials,
- the recycling rates, and
- the transport data.

Ranking procedure

For the potential global warming, acidification, photochemical ozone formation and nutrient enrichment, a formal ranking is presented in tables S.1 and S.2. This ranking reflects what differences between the systems are considered to be significant. It takes the uncertainties mentioned above into account. However, it should be stressed that the assessment and the ranking is based on Danish conditions.

The differences between beer and soft-drink packagings are fairly small. This means the same conclusions hold for 33 cl beer containers and for 33 cl soft-drink packagings.

33 cl packagings

The energy demand, potential global warming, acidification, nutrification and photochemical ozone formation, are significantly lower for the refillable glass bottles than for the disposable glass bottles of the same size (see Table S.1 and section 10.4). The reason is that recycling of glass demands more fuel and electricity than washing and filling of refillable bottles.

Table S.1
Environmental ranking order of existing and alternative 33 cl packagings for beverages that are filled and sold in Denmark.

Environmental impacts	Refillable glass bottle	Disposable glass bottle	Aluminium can	Steel can
Global warming	1-2	2-4	1-3	3-4
Photochemical ozone	1-2	2-4	1-3	3-4
Acidification	1-2	3-4	1-2	3-4
Nutrient enrichment	1-2	3-4	1-2	3-4

Refillable glass vs. aluminium

The differences in potential global warming, photochemical ozone formation, acidification, and nutrient enrichment between the refillable glass bottle and the 33 cl aluminium can are not significant due to the large uncertainties in the environmental impacts of the long-term marginal production of base-load electricity. However, the global warming potential is significantly lower for the refillable glass bottle than for the aluminium can if the marginal electricity to a large extent is based on fossil fuel. The acidification potential is significantly lower if the marginal electricity to a large extent is based on fossil fuel other than natural gas. And the nutrification potential is significantly lower if the marginal electricity to a large extent is based on the combustion of any fuel (see also section 10.4 and section 2.7.3).

The electricity demand is significantly lower for the refillable glass bottle than for the aluminium can. The demand for fossil fuel as process energy and vehicle propellant is lower for the aluminium can, but if the marginal electricity production is based on fossil fuel, the total demand for fossil fuel is significantly higher for the aluminium can than for the refillable glass bottle.

Aluminium vs. steel

Aluminium cans are likely to be environmentally superior to steel cans with aluminium lids, as long as the aluminium lid is not separately recycled. The difference between the environmental impacts of the aluminium and steel cans is relatively small - approximately 20% - but it is significant when the collection rate is in the order of 90%, if recycled aluminium and steel replace 100% primary metals. This conclusion is valid for the potential global warming, acidification, nutrification and photochemical ozone formation. The fossil fuel demand is also significantly lower for the aluminium can than for the steel can. These relations hold for 50 cl cans as well as for 33 cl cans and for beer cans as well as for soft-drink cans. The main reason for the these differences is that the demand for primary aluminium is higher in the steel can system - because the aluminium is lost in the steel recycling process - and that the steel can system in addition demands tinsteel (see also section 11.4).

50 cl soft-drink packagings

The energy demand, potential global warming, acidification, nutrification and photochemical ozone formation, are significantly lower for the refillable PET bottles than for the disposable PET bottles of the same size (see Table S.2 and section 14.4). The conclusion is valid for 150 cl bottles as well as for 50 cl bottles. The reason is that recycling of PET demands more fuel and electricity than washing and filling of refillable bottles.

Table S.2
Environmental ranking order of existing and alternative 50 cl packagings for beverages that are filled and sold in Denmark.

Environmental impacts	Refillable PET bottle	Disposable PET bottle	Aluminium can	Steel can
Global warming	1	2-4	2-3	3-4
Photochemical ozone	1-3	4	1-2	2-3
Acidification	1-2	4	1-2	3
Nutrient enrichment	1-2	2-4	1-3	3-4

Refillable PET vs. aluminium

Our results indicate that the potential global warming, acidification, and nutrification are much lower for the 50 cl refillable PET bottle than for the other 50 cl soft-drink packagings, including the aluminium can. However, the uncertainties in these results are large. As a result of these uncertainties, we do not consider the differences between refillable PET bottles and aluminium cans in acidification, nutrification and photochemical ozone formation to be significant. Only the difference in global warming potential is significant (see also chapter 13).

The electricity demand is significantly lower for the 50 cl refillable PET bottle than for the 50 cl aluminium can. If the marginal electricity production is based on fossil fuel, the total demand for fossil fuel is also significantly lower for the refillable PET bottle than for the aluminium can.

Improvements in the packaging systems

Many environmental improvements can be made within the systems. It was not the purpose of this study to search for such improvement options, but two important options are still identified. The LCA results of the steel can would probably be significantly improved if the aluminium lid is remelted to secondary aluminium instead of being oxidised at the steel recycling. The LCA results for the refillable bottles might be significantly improved through improved energy efficiency at the washing of bottles (see also section 15.2).

Improvements in the LCA

The assessment performed in this project can be further improved. The most important potential improvements include a refined analysis of the markets for recycled material and the electricity market, and improved data for Sr and Hg emissions (see also section 15.4).

1 Introduction

1.1 Life cycle assessment

Environmental life cycle assessment (LCA) is the calculation and evaluation of the environmental impacts associated with the life cycle of a product, material or service (ISO 1997a). Environmental loadings refer to demand for natural resources and to emissions and solid waste. The life cycle consists of the processes and transports involved in raw materials extraction, production, use and waste management. LCA is sometimes called "cradle-to-grave" assessment.

LCA framework

An LCA is divided into four phases. In accordance to the current terminology of the International Organization for Standardization (ISO), the phases are called goal and scope definition, inventory analysis, impact assessment, and interpretation (see Figure 1.1).

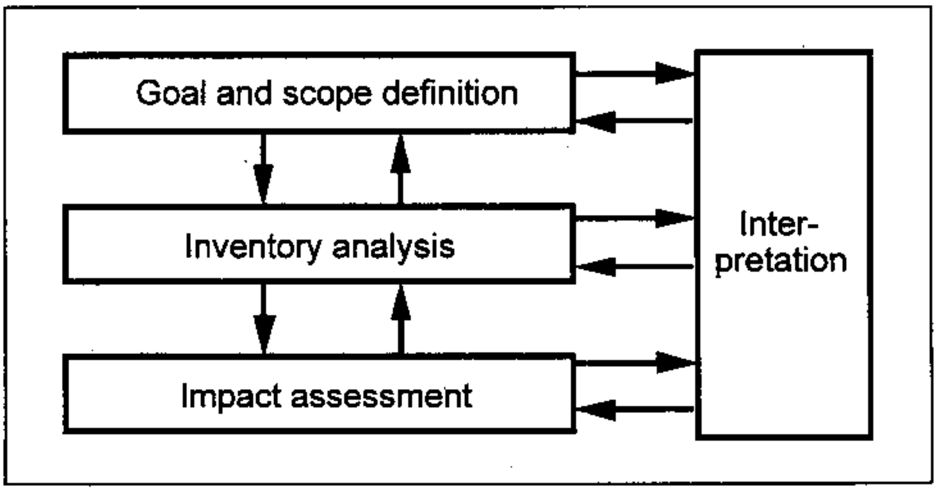

Figure 1.1
Illustration of the phases of an LCA. Source: ISO 1997a.

Goal and scope definition

In the first phase the purpose of the study is described. This description includes the intended application and audience, and the reasons for carrying out the study. Furthermore, the scope of the study is described. This includes describing the limitations of the study, the functions of the systems investigated, the functional unit, the systems investigated, the system boundaries, allocation procedures, data requirements and data quality requirements, key assumptions, the impact assessment method, the interpretation method, and the type of reporting.

Inventory analysis

In the inventory analysis, data are collected, interpreted and presented. Mass flows and environmental inputs and outputs are calculated and presented.

Impact assessment

In the impact assessment, the environmental impacts are evaluated. The impact assessment can be divided into three sub-phases: classification, characterisation and weighting. In the classification, the parameters used in the inventory analysis are sorted into different environmental effect categories. In the characterisation, the potential contribution of the environmental loadings to each effect category is calculated. In the weighting, finally, the total environmental impact of the life cycle is assessed.

Interpretation

Interpretation is the phase in which the results from the inventory analysis and the impact assessment are analysed from a perspective consistent with the defined goal and scope. The purpose is to reach relevant conclusions and recommendations.

An LCA is generally an iterative process. The impact assessment helps increasing the knowledge on what environmental inputs and outputs are important. This knowledge can be used in the collection of better data for an improved inventory analysis.

The results and conclusions of the LCA should also be compared to the goals defined at the beginning of the study. If the goals are not fulfilled, the LCA may have to be improved, or the goals may have to be adjusted.

1.2 The outline of this study

Screening analysis

The parts of an LCA demanding most time and resources are data collection, data interpretation, and reporting. In order to use resources efficiently, this project started with a screening of the previous study. The purpose of this screening was to identify significant points for the updating of the LCA. The screening was based on based on the EDIP impact assessment method (Wenzel *et al.* 1997) and the reports from the previous study (Pommer & Wesnaes 1995, Pommer *et al.* 1995a-f, Wesnaes 1995, and Wesnaes 1996). The screening was performed by answering the following questions:

- Which environmental impact categories are the most important?
- Which emissions give the largest contribution to the important environmental impact categories ?
- Which consumed resources are the most important ?
- Which waste category contribute the most to the waste categories?
- Which processes contribute the most to the above mentioned emissions, consumed resources and wastes?
- What is the most important sources of uncertainty on the data?
- Have important data been omitted in the previous study?
- What errors in the previous study have been identified?
- Which assumptions and preconditions are important for the result?
- Which comments from interested parties are relevant for the updating?
- What new developments or information are relevant for the updating?

Updated study

The results of the screening analysis form the background for the data collection strategy used in this update study. The data collection strategy is presented in Annex D.

Updated data were collected for most parts of the systems investigated. The data collection procedure is presented in section 2.10. Data and calculations on each investigated system are presented in technical reports. Data on transports, electricity production, and the production and use of fuels are presented in a separate technical report. This report includes the goal and scope definition and a summary of the results for each separate system. It also includes the comparisons between the systems. For further information, see section 2.14 below or the Preface above.

2 Goal and Scope Definition

2.1 Goal of the study

Goal

The goal of this study is to update the life cycle assessment (LCA) comparing the potential environmental impacts associated with different existing or alternative packaging systems for beer and carbonated soft drinks that are filled and sold in Denmark. The updated comparison will improve the basis for possible decisions on packaging systems in Denmark. It should be noted that LCA results only are part of the basis for such decisions.

Update

The study is an update of a previous study performed in the period 1992 to 1996 (Pommer & Wesnaes 1995, Pommer *et al.* 1995a-f, Wesnaes 1995, and Wesnaes 1996, below referred to as the "previous study") based on data for 1992-1993. Compared to the earlier study, the following changes are done (see also Annex A):

- data are improved and updated
- conditions which have changed since the previous study are taken into account
- the international standard ISO 14040 (ISO 1997a) and the draft standard ISO FDIS 14041 (ISO 1998) are used, and
- the LCA methodology developed within the Danish project on Environmental Design of Industrial Products (EDIP; Wenzel *et al.* 1997) is used, including the most recent developments within this methodology.

Context

At present, the Danish regulation allows only refillable packagings to be used for beer and carbonated soft drinks filled and sold in Denmark. Thus, the potential environmental impact of other packaging systems where the packaging material is recycled will be compared to the present refillable packaging systems. It is assumed that all the analysed systems will operate under a return scheme, similar to the one presently in operation in Denmark for refillable glass bottles, in which a deposit is paid by the consumer along with the beverage and paid back when returning the package to the retailer. The assumptions on collection rates are presented in section 2.7.2.

Intended audience

The reports from this project are intended for general publication.

2.2 Limitations and applicability

Project framework

As stated in the introduction, this report was produced during the period December 1997 to May 1998. The entire project was scheduled for May 1997 to May 1998.

Impacts considered

Work environment is not included in this study. Nor are impacts from the use and misuse of the products included. This means that, *e.g.*, the potential effects of littering and migration from the packaging to the beverage are not included.

Data collection

An initial limitation in the project was that the data collection only included contacts with data suppliers involved in the earlier project (Anon. 1997). For other processes literature data should be used. However, a few exceptions to this rule were made to obtain good data on materials production etc. For information on the quality of the data used in the LCA, see the data quality assessments in Technical reports 1-7.

Applicability

We expect the results and conclusions from this study to be valid for the situation in Denmark today and a few years ahead.

While some of the data in this study may also be useful for other purposes, the nature of the data needed when making a comparison is not necessarily identical to that needed for other applications, such as environmental declarations, or for identifying improvements options *within* the studied systems. In particular, it can be noted that the calculations on the distribution take not only the packagings but also the beverage into account. Consequently, the results for the individual packaging systems should not be used to identify the main impacts in the life cycle of the packaging, without adjusting for the included beverage. In general, any conclusions of this study outside its original context should be avoided.

2.3 Function and functional unit

Individual systems

The function of the packaging systems is to facilitate containment, distribution and storage of beer and/or carbonated soft drinks from the breweries via retailers to the consumers. In the assessment of the individual systems (chapters 3-8), the functional unit is packaging and distribution of 1000 litres of beverages. The distribution is included in the functional unit to stress the fact that the assessment includes not only the different packagings but also the distribution of the beverage (see section 2.5). The magnitude of the functional unit (1000 litres) is the same as was used in the inventory analysis in the previous study. It also makes it easy to compare our results to the results of other studies.

Comparisons

When the different systems are compared (chapters 10-15), the functional unit is based on the average annual consumption of the relevant beverage for one person in Denmark in 1993: 128.2 litres of beer and 72.3 litres of carbonated soft drinks. These amounts were used in the impact assessment of the previous study. This functional unit makes it possible to see - from the normalisation results - how much the packaging and distribution of beer and carbonated soft drinks affect the environment compared to the total environmental impacts of an average person. Normalisation and other impact assessment results based on the average annual consumption in 1996 are included in Annex B.

The magnitude of the functional unit does not affect the conclusions of the comparison. It is only a scale factor which is identical for the different packaging systems.

2.4 The systems investigated

The packaging systems

The LCA includes different versions of six different packaging systems (see Table 2.1). These cover the most commonly used packaging materials for beer and carbonated soft drinks in Denmark and adjacent markets in Europe.

The packaging systems include the life cycle of the primary packaging: the bottle or the can. They also include the life cycles of secondary packagings - *e.g.*, polyethylene crates, cardboard boxes and corrugated trays - and transport packagings - *e.g.*, wooden pallets. Each investigated system is described in detail in a separate report (Technical reports 1-6). They are also illustrated by process trees later in this report (Chapters 3-8).

Table 2.1
The packaging systems included in this study.

Packaging systems	Beer	Soft drinks
Refillable glass bottles	33cl, green glass	25cl, colourless glass
Disposable glass bottles	33cl, green glass	33cl, colourless glass
Aluminium cans	33cl and 50cl	33cl and 50cl
Steel cans	33cl and 50cl	33cl and 50cl
Refillable PET bottles		50cl and 150cl
Disposable PET bottles		50cl and 150cl

The comparisons

The actual comparisons made in this project are described in chapter 9. We only compare packagings of the same size: *e.g.*, 50 cl cans to 50 cl bottles. Comparisons between containers of different sizes require particular attention, because the size of the packaging is likely to affect the beverage consumption. Furthermore, containers with different sizes fulfil partly different functions. A small container makes it possible to by beverage in small quantities.

Packagings of different sizes were compared in the previous study (see, *e.g.*, Wesnæs 1996). The effect on the container size on beverage consumption and the different functions of packagings with different sizes were disregarded in this comparison. Under these circumstances, the results indicate that a packaging system with large containers cause less environmental impact per 1000 l beverage than a similar packaging systems with smaller containers.

Mixed systems

In reality, there will be a mixture of packaging systems. It can be argued that when several packaging systems exist in parallel, the efficiency of the distribution and the processes at the retailers will be affected. However, the effects on the distribution are not expected to be significant (Jacobsen 1998), and the environmental impacts of the retailer are relatively small (see below). This means the systems can be investigated individually.

A study on individual systems will not provide good information on how large the consequences of a decision on packaging systems would be, but it will show if the consequences are good or bad for the environment. It will not give the magnitude, but it will indicate the direction.

2.5 System boundaries

Basic criteria

An LCA should include all processes contributing significantly to the environmental impacts of the system investigated. In a comparative LCA, it is particularly important to include all processes where the difference between the systems is significant. When the results are intended to form part of the basis for a decision - as in this case - the LCA should include all processes that are significantly affected by the decision. A decision on national standards for packaging will, of course, affect the packaging systems, but it will also have a significant impact on other systems. As illustrated by Figure 2.1, the systems investigated in this study do not only include the packaging systems, but also parts of other product systems that are significantly affected by the choice of packaging system.

In all LCAs, data collection is restricted by the specific limitations of the project. For the limitations of this project, see section 2.2. Our data collection efforts have been focused on processes where preliminary calculations, the screening analysis (see section 1.2) or earlier experience indicate that the difference in environmental impacts can be significant. The most important omissions and system expansions are described in the following. The effects of the omissions are discussed in section 2.13.2.

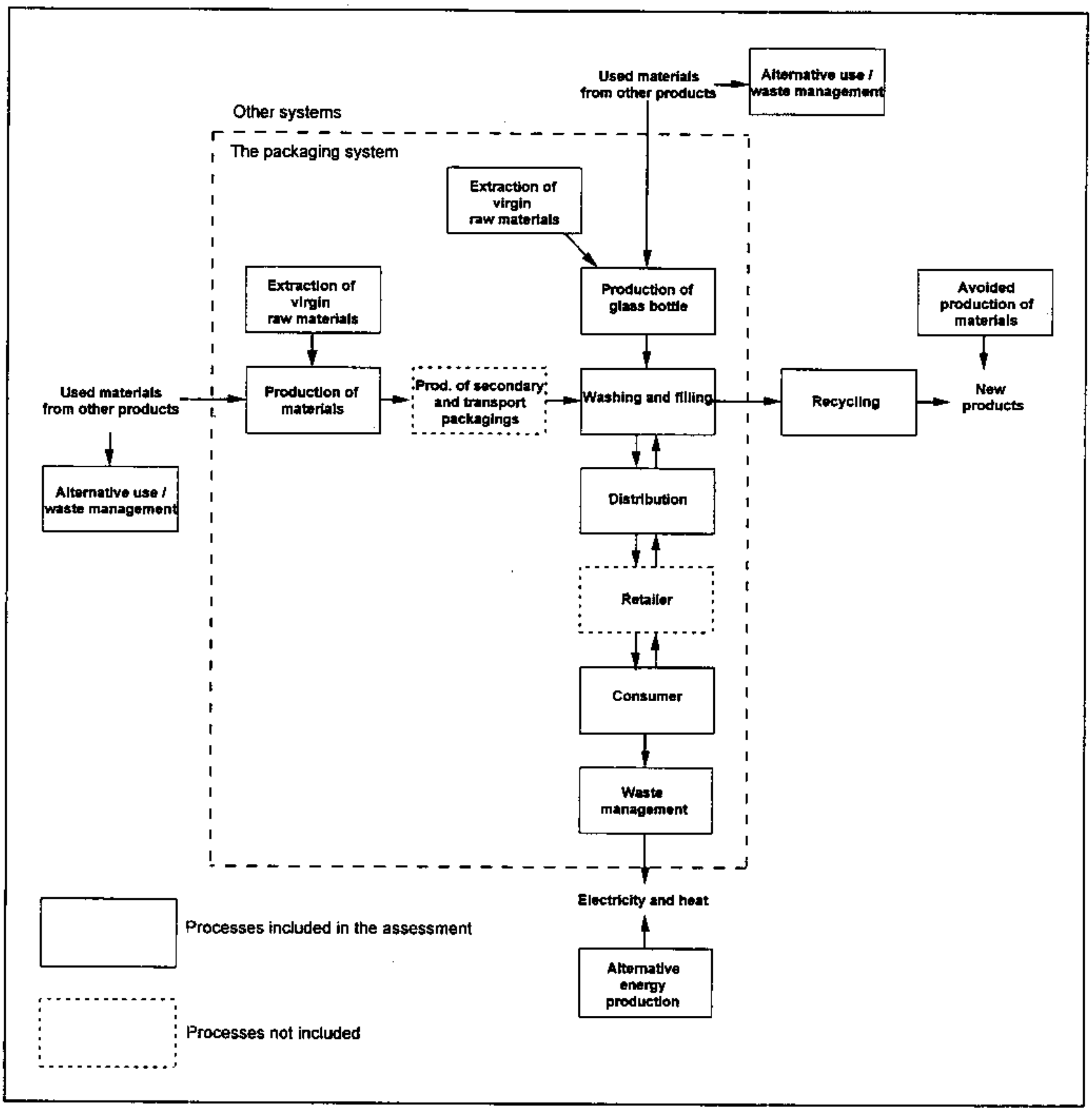

Figure 2.1
Simplified illustration of the system investigated. The illustration is valid for refillable glass bottles. Transports other than the distribution of beverage are not included in this illustration, nor is production of caps and labels, but these are included in the LCA.

Geographical boundaries

As stated above, the LCA concerns only beverage packagings that are filled and also sold in Denmark. However, the packaging systems include several processes that are located outside Denmark, *e.g.*, the production of various materials. These processes are included in the LCA.

Primary packaging

The systems investigated include the whole life cycle of the primary packaging: production of materials, production of packaging, washing and filling at the brewery, refrigeration at the consumer, recycling of the container and waste management of the share that is not recycled. The environmental impacts of sorting and other processes at the retailer are excluded from the LCA. The effect of this omission on the total energy demand is in the order of 1% for the refillable bottles (see sensitivity analyses in Technical reports 1 and 5). For cans and disposable bottles, the effect of the omission is smaller. As indicated above (section 2.2), impacts on work environment are not included in this study.

Secondary and transport packagings

The systems investigated include production of materials for secondary and transport packaging. They also include recycling and waste management of these materials. The manufacture of secondary and transport packagings, *e.g.*, moulding of crates, folding of boxes etc. is excluded from the LCA due to lack of data. In our experience, the environmental impacts of these processes are generally small compared to the environmental impacts of materials production (see, *e.g.*, Tillman *et al.* 1992).

Distribution/transportation

The systems include transports of packaging materials and packagings. It also includes the distribution of the beverage (incl. packaging) from the brewery to the retailer, and the return transport of empty packagings. The motive for including the distribution of the beverage is that the efficiency of the distribution varies between the different packaging systems. The choice of packaging system affects the number of truck loads required for the distribution. The distribution of the beverage was not included in the previous study.

The LCA does not include the transports between retailer and the residence of the consumer. The effect of the packaging on these transports is less than 1% of the total energy demand of the systems (see chapter 6 in Technical report 7 and the sensitivity analysis in Technical report 1; see also the discussion on assumptions in section 2.7.1).

Energy production

The systems investigated include production of the energy carriers - electricity and fuels - which are used in the processes and transports of the packaging systems. It also includes production of the energy carriers that are used in the production of these energy carriers.

Waste management

The systems investigated include incineration and landfilling of consumer waste. The systems are expanded to include parts of other life cycles that are affected by energy recovery at waste incineration (see Figure 2.2 and sections 2.6-2.7). A similar expansion of system boundaries was made in the previous study.

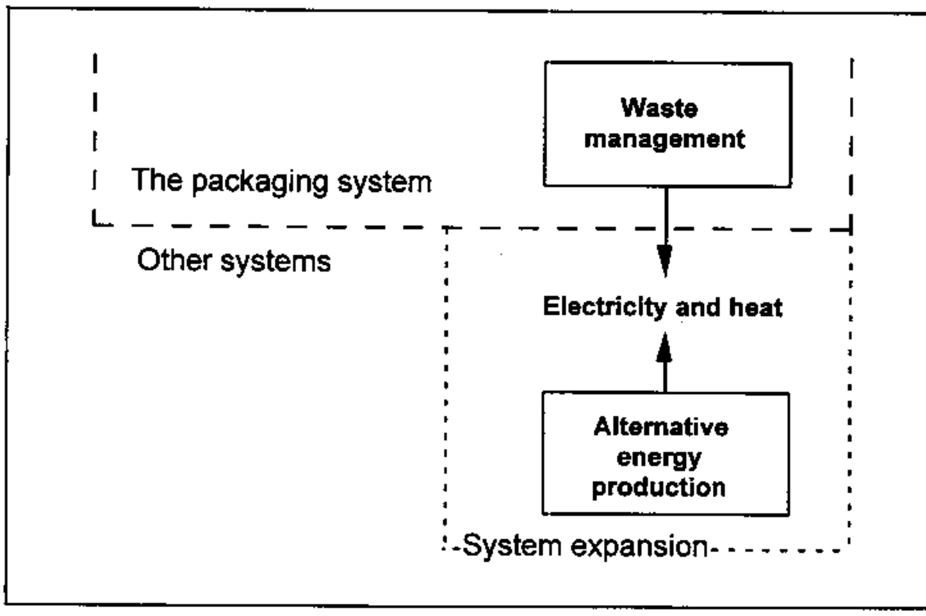

Figure 2.2
The systems investigated are expanded to include the energy production replaced through waste incineration with energy recovery.

The landfill is considered a part of the technological system until the end of the methane phase - which is typically in the order of a century. After the methane phase the landfill is considered a part of nature. This means that the environmental outputs from landfilled material are the emissions during this foreseeable time period plus the waste remaining in the landfill at the end of the methane phase.

Landfilling of waste from production processes is not included in the system investigated, nor is landfilling of slags and ashes from waste incineration. These are non-elementary outflows from the system, *i.e.*, outflows which are not followed to the boundary between technosphere and nature. The amounts of slags and ashes are relatively large from glass bottles, steel cans and aluminium cans in waste incineration plants. However, the energy demand is small for the transport to landfill and for the processes at the landfill. The emissions from the deposited slags and ashes are also likely to be small in the foreseeable time period.

Recycling

The systems investigated are expanded to include parts of other systems that are affected by the use of recycled material in the packaging system (see Figure 2.3), or by recycling of major materials after use in the packaging system (see Figure 2.4). These system expansions were not made in the previous study.

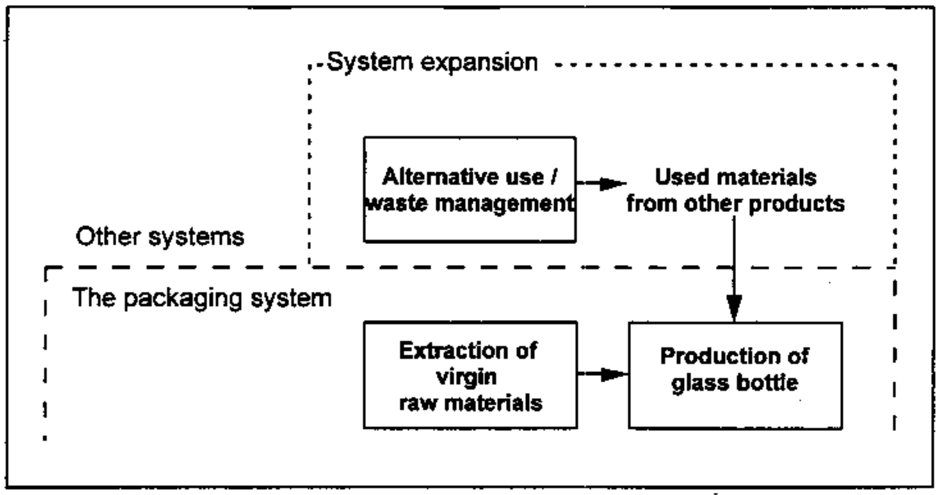

Figure 2.3
The systems investigated are expanded to include parts of other life cycles that are affected by the use of recycled material in the packaging system. The illustration is valid for production of glass bottles.

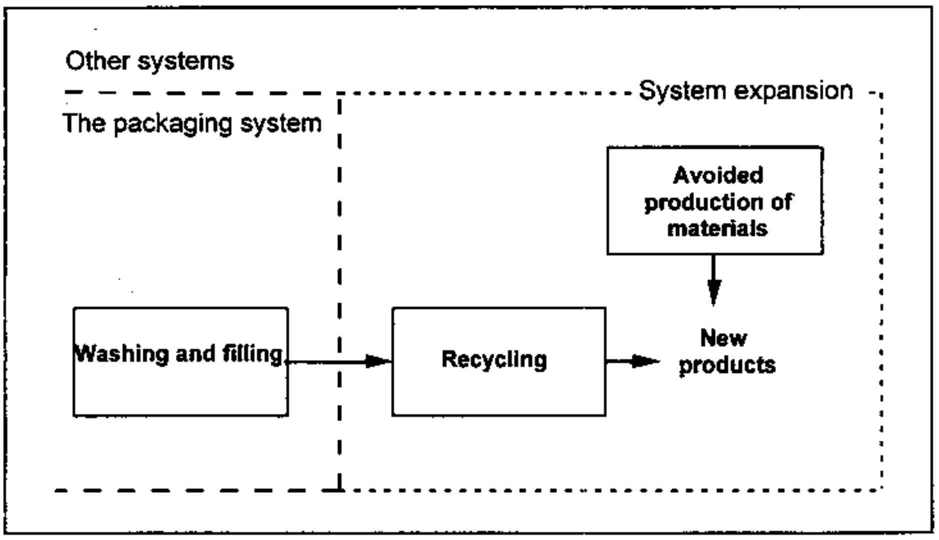

Figure 2.4
The systems investigated are expanded to include parts of other life cycles that are affected by recycling of material from the packaging system. The illustration is valid for refillable bottles.

If an outflow of recycled material is small (less than 1% of the weight of the primary packaging), the system is not expanded. Instead, the recycling process and the effects on other systems are cut off from the LCA. These outflows are reported as non-elementary outflows from the system investigated. The one percent limit is chosen to obtain a manageable number of system expansions. We consider it to be reasonable since none of the small outflows is expected to have large toxic or extremely energy intensive impacts on other product systems.

For further details on the method used for dealing with open-loop recycling, see sections 2.6.2 and 2.7.5.

Ancillary materials

A large number of ancillary materials are used in the packaging systems. These include coatings for steel and aluminium cans, NaOH for washing of refillable bottles, chemicals for pulp and paper production, etc. In our initial calculations the production of most of these materials was not included. After a sensitivity analysis, we decided to include the production of the main coatings and the NaOH used for the washing of refillable glass bottles. The production of these materials was not included in the previous study.

For many ancillary materials, the production is still not included. These materials are reported as non-elementary inflows to the systems, *i.e.*, inflows which are not followed to the boundary between technosphere and nature. The amounts used of these materials are generally small, and the environmental significance is estimated through a sensitivity analysis (see section 2.13.2).

Capital equipment

The production and maintenance of capital equipment (breweries, factories, trucks, shops etc.) are excluded from the study. They are not likely to have a significant effect on the total LCA results. The most important processes in the systems are the distribution and energy intensive processes such as materials production (see dominance analysis, section 5.1 in Technical reports 1-6). Capital equipment does not contribute significantly to the environmental impact of energy intensive processes (see, *e.g.*, Brännström-Norberg *et al.* 1996). The production of trucks is not significant compared to the use of trucks (Eriksson *et al.* 1995).

Overhead operations

For many of the processes, we do not know whether lighting, heating and other overhead operations are included in the data. However, the uncertainty introduced in this way is not significant. Overhead operations do not contribute significantly to the environmental impact of energy intensive processes (Brännström-Norberg *et al.* 1996).

2.6 Allocation procedures

The ISO procedure

The following stepwise allocation procedure is required by ISO FDIS 14041 (ISO 1998):

Avoiding allocation

The first step of the procedure is: "wherever possible, allocation should be avoided by dividing the unit process to be allocated into two or more sub-processes and collecting the environmental data related to these sub-processes, or by expanding the product system to include the additional functions related to the co-products."

The particular advantage of avoiding allocation through system expansion is that the LCA can also reflect the actual consequences of the decision on the environmental inputs and outputs of other life cycles. As discussed below, several allocation problems were avoided through system expansion.

Physical causalities

The second step of the ISO procedure is: "where allocation cannot be avoided, but the amount of the co-products can be independently varied, the allocation should be done in a way which reflects the underlying physical causal relationships between the products and the environmental inputs and outputs of the system." No such allocations were made in this study.

Other relationships

The third and final step of the ISO procedure is: "where physical causal relationships alone cannot be used as the basis for the allocation, economic or other relationships should be used instead."

Our interpretation

The ISO draft does not explicitly state that the "other relationships" should be causal relationships. However, we believe this is a reasonable interpretation, since otherwise any arbitrary allocation would be allowed.

Justification etc.

The applied procedures for allocating environmental exchanges to the different products shall be documented and justified for each unit process for which allocation is made. Uniform allocation procedures shall be applied to all similar products entering or leaving the studied product systems. Whenever several alternative allocation procedures seem applicable, a sensitivity analysis shall be conducted to illustrate the consequences of the alternative approaches.

The allocation procedures used in this project are described below. The assumptions made when expanding system boundaries are described and discussed in section 2.7.

2.6.1 Co-product allocation

System expansion

To contribute to decision-making, the LCA should supply information about the environmental consequences of the decision contemplated. When allocation is avoided through system expansion, the LCA can supply information on the consequences of the decision on the environmental inputs and outputs of other life cycles. For this reason, we expanded system boundaries when this was possible.

Waste incineration

As indicated above (Figure 2.2), the system was expanded to include the alternative energy production which is avoided through waste incineration in the packaging systems. Hence, allocation was avoided. The effect of this system expansion strongly depends on what energy sources are assumed to be replaced by energy from waste incineration (see section 2.7.4).

Aggregated data

Data on production of plastics such as polyethylene terephtalate (PET) and low density polyethylene (LDPE) were based on reports from the Association of Plastics Manufacturers in Europe (APME; Boustead 1993, 1995). The data in these reports are aggregated, allocated data. The allocations are based on physical properties of the products (Boustead 1992), not on causal relationships - physical or otherwise. This means that the allocation is not performed according to the interpretation of the ISO requirements discussed above. The APME data are not adequately disaggregated to allow recalculation according to this interpretation. In spite of this, we prefer to use these data rather than older, disaggregated data from other sources.

The use of aggregated APME data can have a significant effect on the results for the PET bottle systems. For the other systems, the effects on the total LCA results are likely to be very small since the amount of plastics used in the systems is small.

Co-generation of electricity and heat

In one of our electricity scenarios, we used data on average EU electricity production mix. This mix includes some co-generation of electricity and heat. In the co-generation, the allocation was based on the exergy of the electricity and heat. The exergy was used as an approximation of the economic values of the product. This allocation has no effect on the base case calculations. However, it has a small effect on the sensitivity analysis. For further details, see Technical report 7.

Cut-off

When the amount of co-products was very small (typically much less than 1% of the weight of the primary packaging) the effects on other life cycles were cut off from the system. These co-products are reported as non-elementary outflows from the system investigated. We do not have methods to estimate the environmental significance of these flows.

2.6.2 Open-loop recycling

System expansion

As indicated above (Figures 2.3 and 2.4), we avoided allocation by system expansion in the following cases:

- Use of recycled material in the packaging systems
- Recycling of material after use in the packaging system.

The results of the first system expansion strongly depend on what is assumed to be the alternative fate of the material if it was not used in the packaging system. The results of the second system expansion depend equally strongly on what material is assumed to be replaced by recycled material from the packaging system. For further details, see section 2.7.5.

Closed-loop approach

An exception from the rule above was the recycling of aluminium. We used a closed-loop approach in this case: in our calculations, all aluminium cans collected for recycling are recycled into new cans. This was done for the following reasons:

- in reality, a significant share of the aluminium cans are recycled into new cans,
- no updated data on the share of recycled material in the aluminium cans were available within this project, and
- the closed-loop approach gives the same results as a system expansion. In the closed-loop approach, the remelted aluminium is assumed to replace virgin aluminium in the packaging system. In the system-expansion approach, the remelted aluminium would be assumed to replace virgin aluminium in other product systems (see also section 2.7.5).

Cut-off

When the outflow of recycled material was small (less than 1% of the weight of the primary packaging) the effects on other life cycles were cut off from the system. These recycled materials are reported as non-elementary outflows from the system investigated. The effects of this cut on the total LCA results are clearly small. First, the non-elementary outflows are very small. Second, the system investigated does include primary production of the materials.

2.7 Key assumptions

The most important assumptions are described and discussed in this section.

2.7.1 Consumer behaviour

We assume consumer behaviour to be largely independent of the packaging system. The consumption of beer and carbonated soft drinks is assumed not to be significantly affected by the choice between packaging system. This assumption is reasonable since we only compare beverage containers of the same size. However, the lighter packaging makes them easier for the consumer to carry. This could, potentially, lead to an increase in beverage consumption.

The number of shopping occasions is assumed to be the same for all systems. The mode of transportation from the retailer to home is also assumed not to be affected. In reality, the mode of private transports may be affected by the choice of packaging system. Lighter beverage packagings may result in less people using the car for shopping.

Finally, the decision to drink directly from the container or to pour the beverage into a glass is assumed not to be affected by the choice of packaging. If the drinking process is affected, then the washing of drinking glasses would also be affected by the packaging system.

2.7.2 Recycling rates

As indicated above (section 2.2) we assumed that all the analysed systems will operate under a return scheme, similar to the one presently in operation in Denmark for refillable glass bottles. Of the refillable bottles 98.5% are assumed to be collected for recycling. The collection rate for cans and disposable bottles is assumed to be 90%. The same assumptions were made in the previous study. Some of the collected refillable bottles are discarded at the washing and filling processes. As a consequence, the actual reuse of bottles is lower than the collection rates (see Table 2.2).

In a sensitivity analysis, the collection rate for refillable bottles was assumed to be the same as for the other containers, *i.e.* 90% (see section 2.13). We also calculated the emissions from an aluminium can system with 98.5% collection rate.

Table 2.2
Collection, reuse and recycling rates for the packagings included in this study. References: Pommer & Wesnæs (1995), Jacobsen (1997).

Packaging	Collection rate [%]	Discarded at filling [%]	Reuse of bottles [%]	Material to recycling [%]	Waste disposal [%]
Refillable glass bottle	98.5	1	97.5	1	1.5
Disposable glass bottle	90	-	-	90	10
Aluminium can	90	-	-	90	10
Steel can	90	-	-	90	10
Refillable PET bottle	98.5	3.5	95	3.5	1.5
Disposable PET bottle	90	-	-	90	10

2.7.3 Electricity production

For electricity production there is a large difference between the environmental impacts of different production technologies. The choice of electricity scenario therefore requires careful consideration.

Previous study

In the previous study, electricity was assumed to be average electricity for Denmark, Sweden, Western Europe or the world, depending on where the electricity was used. Two alternative scenarios were constructed for a sensitivity analysis on the results from the inventory analysis. In one of these, all electricity was assumed to be average electricity from Western Europe. In the other alternative scenario, all electricity was assumed to be average Danish electricity, *i.e.*, mainly based on coal. The scenario with average electricity from Western Europe was also used in a sensitivity analysis on the results from the impact assessment.

Ideal data

As discussed below (section 2.9.1), the most relevant data to use in this study reflect the long-term marginal technology. In the electricity sector it is also important to distinguish between base load and peak load. Most of the electricity used in the packaging systems are demanded by industrial processes. It is part of the base-load demand for electricity, rather than the peak-load demand. This means that the most relevant electricity data for this study reflect the long-term base-load marginal.

Modern coal condensing

The base case electricity scenario for this project is the long-term base-load marginal for the EU. This electricity production is determined in view of the planned de-regulation of the European electricity markets which is assumed to be integrated in the current capital investment. This implies - given adequate transmission capacities - that the marginal technology is the same all over Western Europe (EU). In view of the current production costs and the constraints on the different technologies, it is likely that the long-term base-load marginal for a de-regulated electricity market in EU is modern coal condensing electricity production.

Fragmented markets

As a part of this project, an international panel was set up to assist in selecting the correct electricity scenario (see Annex C). The panel concluded that: "The electricity markets in Europe are still relatively protected, fragmented markets, which makes it necessary to determine the actual marginal in each specific market (determined by country or production company). This should be done empirically as part of the project. It is not possible in advance to estimate if the result will be that the same technology is marginal in all markets." In Technical report 7 it is substantiated that if the electricity market in the EU is fragmented, it can be considered to contain three separate markets, each with their own electricity marginals. In the Nordic countries, the long-term base-load marginal electricity is based on natural gas. In Greece, the marginal electricity is based on lignite. In other EU countries, it is based on coal.

In accordance with the conclusion from the panel and the analysis of the fragmented markets (see Technical report 7), an alternative electricity scenario was constructed where the electricity used in the Nordic countries is based on natural gas, while the electricity used outside the Nordic countries is based on coal condensing. This scenario is consistent with the conclusions of the panel and the analysis since the processes in the packaging systems are mainly situated in northern or central Europe. The scenario was used in the sensitivity analyses (see section 2.13.2).

Natural gas

For the sensitivity analyses, a third electricity scenario was constructed where the electricity is based on natural gas only. The purpose of this scenario is to assess the importance of our conclusions regarding what is the long-term base-load technology for electricity production.

Additional uncertainty

The main electricity scenario and the scenario with fragmented markets described above result from a mainly economical analysis. They are based on the assumption that the production constraints are unaffected by changes in the electricity demand (see section 3.2 in Technical report 7). However, production constraints may be affected by changes in the demand. This is particularly true for political constraints. The most obvious example concerns Swedish nuclear power. It is related to the idea of fragmented electricity market mentioned above.

A political decision has been taken to phase out Swedish nuclear power. There is currently a heated political debate over the time plan for this nuclear phase out (see, *e.g.*, Anon. 1998). In this context, a significant increase in the Swedish electricity demand may cause the phase out to be delayed. Consequently, if the electricity market is fragmented - as discussed above - the long-term marginal electricity production in Sweden may for the next few years be a mixture of old nuclear power plants and new power plants using fossil fuel. The ratio of nuclear power to fossil fuel is unknown. The Swedish marginal electricity production may be mainly based on nuclear fuel, or it may be mainly based on fossil fuel.

Swedish nuclear power cause much less emissions of CO_2, SO_2, and NO_X compared to coal condensing power (see, *e.g.*, Brännström-Norberg *et al.* 1996). On the other hand, there are problems of radioactive waste etc. The conclusion is that the actual uncertainty in the environmental impacts of the marginal electricity production is quite large. The full uncertainty is taken into account in the conclusions of this study (see, *e.g.*, section 10.4).

Average EU electricity

Yet another electricity scenario is used in the sensitivity analysis, where all packaging systems are assumed to use an average of the EU electricity production in 1994. This scenario allows more easy comparison with the results of other LCAs performed for other purposes, such as, *e.g.*, EU eco-labelling. In this type of LCA, average electricity is typically used as a standard scenario.

Further reading

For further discussion on this issue, we refer to Technical report 7.

2.7.4 Waste management

The long-term marginal waste management technology in Denmark is assumed to be waste incineration with energy recovery. The reason is that Danish legislation prohibits landfilling of combustible waste.

The marginal waste management technology in Europe in general is assumed to be landfilling. The reason is that the amounts of combustible waste available in Europe are generally larger than the available capacity of waste incineration plants (Ekvall & Finnveden 1998).

Energy replaced

The energy recovered at waste incineration is calculated based on data from SK Energi (1994). For each MJ of waste (lower heating value), 0.768 MJ of heat and 0.039 MJ of electricity are produced. This energy is assumed to replace the same amount of heat and electricity produced in other ways. The heat replaced is assumed to be average heat from Danish household boilers, which is based on oil (60%) and natural gas (40%; Eurostat 1997). The electricity replaced is assumed to be the same type of long-term marginal (or average) electricity that is supplied to the packaging system.

Further reading

The waste incineration is further described in Technical report 7.

2.7.5 Materials recycling

One market

Our assumptions regarding the effects of recycling are based on considerations of the mechanisms of the market for recycled material. The effects of using a certain recycled material (Figure 2.3) are connected to the effects of recycling a similar material after use (Figure 2.4). The recycled material flows connect the packaging system to the same market for recycled material (see Figure 2.5). The effects of using recycled material from this market or delivering recycled material to the market depend on the same market mechanisms; they depend on how the market reacts to a change in the supply or demand of the packaging system.

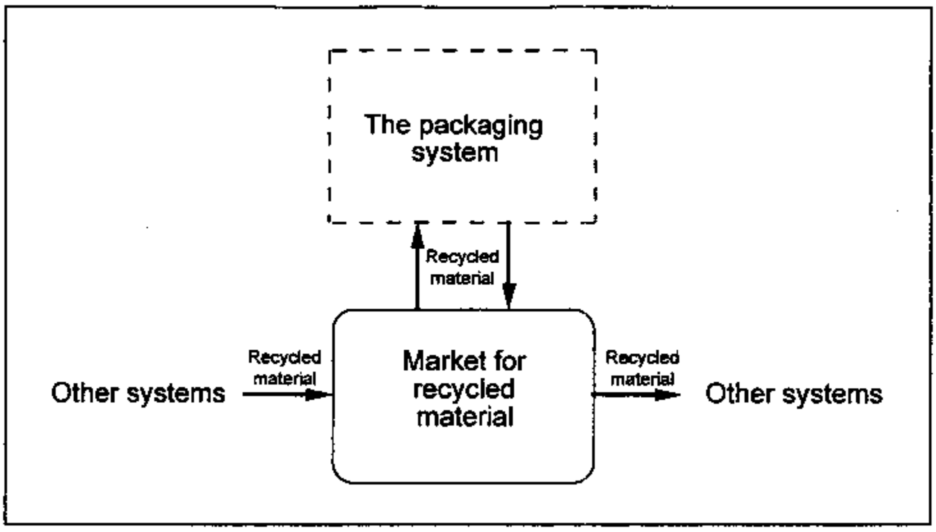

Figure 2.5
The inflows and outflows of a certain type of recycled material connect the packaging system to the same market.

Markets for recycled glass, aluminium and steel

For glass, aluminium and steel we assume that the production of secondary material is mainly limited by the amount of material collected for recycling. All material available for recycling is assumed to be recycled, replacing virgin material. These assumptions are based on the following considerations:

- there is a growing overall demand for the materials,
- the technology and production capacity for recycling of these materials are well established,
- markets for the recycled materials are well established, and
- the recycled materials can be used in most applications.

Glass recycling

Of the disposable glass bottles, 90% are collected for recycling (see Table 2.2). Part of the glass in discarded refillable glass bottles is also recycled. As indicated above, the collected glass is assumed to replace virgin raw materials in other glass products.

Glass bottles are produced in part from broken glass. Since all glass available for recycling is assumed to be recycled, the alternative fate of the broken glass is to be recycled into another product. This means that the use of recycled material in the glass bottles has no effect on the LCA results.

The effects on total LCA results of any uncertainty in these assumptions are small (see sensitivity analysis in Technical reports 1 and 2). There are large flows of recycled glass to and from the disposable bottle systems. However, any error in the effects of the outflow is partly offset by the error in the effects of the inflows. The reason is that the assumptions regarding material replaced and alternative fate of recycled material are connected.

Aluminium cans

Of the used aluminium cans, 90% are collected for recycling. Approximately 10% of the collected aluminium are lost in the remelting process. The remaining, remelted aluminium is assumed to replace the same amount of virgin aluminium in the packaging system. The effects on total LCA results of any uncertainty in this assumption can be significant, because the difference between primary and secondary production of aluminium is large.

Since we use a closed-loop approach for aluminium cans, the inflow of secondary material in our calculations depends on the recycling rate of used aluminium cans. The alternative fate of the secondary aluminium is to be recycled into another aluminium product. Hence, the share of recycled aluminium in the packaging systems has no effect on the LCA results.

Tinsteel cans

Steel scrap may be recycled either in an electric arc furnace (EAF) which is the traditional way of recycling or in a basic oxygen furnace (BOF). In the BOF, carbon contained in primary pig iron is burnt out under injection of pure oxygen. The combustion of carbon generates heat. Steel scrap is added to cool the melt.

Steel cans are produced from tinplate, *e.g.*, a steel alloy with tin. In Germany, 70% of used steel cans are recycled via BOF and 30% via EAF. Scrap from steel can production and waste incinerated steel cans can be assumed to follow the same route (Alding 1997).

It has been argued that tinplate scrap cannot be recycled without risk of reducing the steel quality. The problem of recycling tinplate in EAF is that this process only handles scrap, which already contains a share of alloy metals and other impurities. Increased tinplate recycling via BOF may reduce the steel quality. This problem could be solved by detinning of the scrap, but detinning is difficult for steel cans due to their aluminium lid. Steel cans are generally not detinned before recycling (Hatscher 1997).

In BOF recycling, the tinplate is mixed with approx. 80% primary pig iron without alloys. This means that the quality problem is reduced. Tinplate currently only constitutes approx. 4% of the steel scrap recycled via BOF. For these reasons, increased tinplate recycling via BOF is not likely to cause any problems. Hence, we assume the marginal recycling process for tinplate to be BOF recycling.

Steel recycling

For steel scrap in general, approx. 40% is recycled via BOF and 60% via EAF (Täffner 1997). As indicated above, the amount of scrap in a BOF depends on the amount of energy released in the BOF. It is not affected by changes in the amount of available steel scrap. This means that an increased BOF recycling of, *e.g.*, tinplate means that other steel scrap is displaced. Recycling via EAF has no such restrictions. Hence, we assume the marginal recycling process for steel in general to be EAF recycling.

Consequences of steel can recycling

As indicated above, the lid of the steel cans is produced from aluminium. When the steel cans are recycled in a BOF, the aluminium is oxidised and releases additional energy. As a consequence, the share of scrap in the BOF is increased. The net effect of BOF recycling of 33 cl steel cans is that BOF recycling of other steel scrap is increased. The net effect of BOF recycling of 50 cl steel cans is that BOF recycling of other steel scrap is reduced. The difference is due to the fact that the share of aluminium is larger in the 33 cl can. For further information, see Technical report 4.

As indicated above, production of secondary steel from the packaging system is assumed to replace primary steel.

A small share of steel scrap is used in the production of tinsteel. Since all steel available for recycling is assumed to be recycled, the alternative fate of the steel scrap is to be recycled into another product. This means that the use of recycled material in the steel cans has no effect on the LCA results.

The effects on total LCA results of any uncertainty in these assumptions can be significant, because the difference between primary steel production and EAF recycling is significant (see sensitivity analysis in Technical report 4).

Market for recycled PET

For PET, we cannot judge whether or not the production of secondary material will be limited by the amount of PET available for recycling, by the production capacity for recycling or by the demand for secondary PET. The markets for recycled plastics are relatively new and strongly influenced by political decisions.

PET recycling

Of the disposable PET bottles, 90% are collected for recycling. Part of the plastics in discarded refillable PET bottles is also recycled. The uncertainty in the effects of this recycling is quite large. If production of secondary PET is limited mainly by the amount of PET that is available for recycling, the recycled PET may replace primary PET but it may also replace other materials. If, for example, recycled PET is used to produce textiles, it will replace wool, cotton, nylon or other textile materials.

However, if the recycling is limited by the production capacity for recycling or by the demand for secondary PET, the used PET from the packaging systems will displace used PET from other systems. The displaced PET from other systems will be incinerated or deposited at a landfill.

Due to lack of data, we assume that recycled PET from the packaging system replaces equal amounts of virgin PET and recycled PET from other systems. We believe this will minimise the maximum error introduced. However, the large uncertainty in our assumption is very important for the results of the PET bottle systems (see sensitivity analysis in Technical reports 5 and 6). There are large flows of recycled PET from, in particular, the disposable bottle systems, and the effects of these flows are very uncertain. Errors in the effects of the outflow are not offset by a corresponding error in the effects of the inflows, since there are no inflows of recycled PET to the packaging system.

HDPE recycling

Crates and trays are produced from high density polyethylene (HDPE). These are recycled in a closed loop: when they are discarded, they are regranulated and used for production of new crates and trays (Holm 1997). This means that the regranulated HDPE replaces primary HDPE. The effect on the total LCA results is small since only 0.6% of the crates and trays are discarded after use (Jacobsen 1997).

Other plastics

Other plastics are recycled in small amounts from some of the packaging systems. We do not know whether they will replace virgin or recycled plastics, but we assume that they will replace equal amounts of virgin and recycled material of the same type. The uncertainty involved in this assumption is not important for the LCA results, since the flows of these materials are small.

Board recycling

To avoid serious quality problems in the long term, approximately 20% of the paper fibres must be virgin. We assume that the market will approach and attain a long-term balance at a recycling rate of approximately 80%. At this balance, recycled fibres from the packaging system is assumed to replace a mix of 80% virgin fibres and 20% recycled fibres.

After use in the packaging systems, 20% of the corrugated board and cardboard is recycled (Jacobsen 1997). We assume that the recycled fibres are used for production of testliner which replaces primary kraftliner (80%) and testliner produced from recycled fibres from other systems (20%). The testliner thus replaced is assumed to end up at landfill.

Recycled fibres are also used in the production of corrugated board for the packaging system. The effect of this use of recycled fibres depends on the alternative fate of these fibres. To be consistent with the assumptions above, we assume that the alternative to recycling into the packaging system is recycling into testliner used in other systems (80%) or landfilling (20%).

The uncertainty involved in the assumptions regarding recycling of corrugated board and cardboard is not critical for the LCA results. The flows of recycled fibres are small.

Adherence to ISO

The assumptions made regarding the materials replaced by outflows of recycled materials and the alternative fate of outflows of recycled materials are consistent with the ISO requirement that the allocation procedure shall be similar for similar material entering and leaving the system.

2.8 Data requirements

Comparative study

As stated above (section 2.1), the goal of the LCA presented in this report is to provide information about packaging systems for beverages filled and sold in Denmark. The results should add to the basis for decision-making on packaging systems. For this purpose we require data reflecting the environmental consequences of such decisions. Ideally, we should use data on all environmental inputs and outputs of all processes affected by the decisions. In practice, we use all available data on the environmental inputs and outputs of the processes that are significantly affected.

2.9 Data quality requirements

2.9.1 Technology

Background

As indicated above, we require data reflecting the environmental consequences of decisions on the packaging systems to improve the basis for these decisions. This means that the technologies to study should be the technologies actually affected by changes in the packaging systems. The effects of any changes in the packaging systems - *e.g.*, the introduction of new non-refillable systems - will not affect all technologies equally. For this reason, average data will not accurately reflect the environmental consequences of the decisions.

Specific data

If a specific unit process can be identified to be the one affected, and the actual conditions under which it will operate can be determined, then the specific data obtained from this unit process are the ideal data for the study. This is the case for the packaging manufacturing processes and the distribution system. For these parts of the systems, the ideal data are specific data representing the present technology.

Marginal data

Many unit processes delivers inputs to the rest of the product system through a market. Production of fuels and electricity are examples on such unit processes. Other examples are the production of bulk materials such as steel, aluminium, PET, corrugated board and cardboard. A change in the Danish beverage packaging system will have only marginal effects on these markets. This means that the technology actually affected by a decision is the marginal technology. Hence, marginal data - data representing the marginal technology - should ideally be used for the production of energy and bulk materials.

The waste management systems and markets for recycled materials will also be only marginally affected by a change in the packaging system. Marginal data should ideally be used for these parts of the systems as well.

Short-term marginal

It is important to distinguish between short-term and long-term marginals (see section C.3 in Annex C). The short term is defined as a time period which is not long enough to include investments in new production capacity. In the short term, the production capacity is assumed to be fixed. Only the utilisation of the production capacity can vary. Short-term marginal data reflect the marginal variations in this utilisation.

Long-term marginal

The long term is defined as a period which is long enough to allow for investments in production capacity. Long-term marginal technology is the technology for which the production capacity is affected by changes in the demand.

The decisions studied in this life cycle assessment are expected to affect future capital investment. For this reason, we believe that the most relevant data for this study reflect the long-term marginal technology rather than the short term.

This view is supported by recent methodological developments within the international LCA community (see, *e.g.*, Frischknecht 1997, Heijungs *et al.* 1997, Baumann 1998). In contrast, the previous study was based on site specific or average data.

Identifying the long-term marginal

The long-term marginal technology involved depends on the current trends in the production represented by the unit process. If the production volume of the process is generally decreasing more than the average replacement rate for the capital equipment, the marginal technology can be assumed to be the least preferred technology (typically old, non-competitive). If the production volume of the process is generally increasing - or decreasing less than the average replacement rate for the capital equipment - the marginal technology can be assumed to be the most preferred, unconstrained technology. Thus, if the general production volume of the process is generally decreasing at about the average replacement rate for the capital equipment, the marginal technology may shift back and forth from least to most preferred, which makes it necessary to make two separate scenarios.

2.9.2 Other quality aspects

Time-related

Any decision based on the results from this study will take place in the future. The decisions on packaging systems are to be made in the near future. They can also be revised within a few years. But they might still affect investments in new factories etc. and hence have a long-term impact on the technological system. All this means that we should ideally use data on future environmental inputs and outputs. However, future data can only be obtained through extrapolation, and the uncertainties involved in this procedure are large. For this reason, we do not use data on future technology, but aim at using as recent data as possible.

Geographical

The decision concerns packagings used in Denmark. Hence, we need data on beverage distribution and use in Denmark. We need data on waste management in Denmark. We also need data on the production of materials for packagings used, or potentially used, in Denmark. This materials production may often be located outside Denmark.

Precision, completeness representativeness and uncertainty

To give the best possible contribution to the decision-making, the data should be as precise, complete and representative as possible within the framework of the study. The uncertainty in the data and the results should be minimised.

The LCA method

The methods used in the project should be consistent and reproducible.

Data sources

As stated above (section 2.2), an initial limitation in the project was that the data collection only included contacts with data suppliers involved in the earlier project. A few exceptions to this rule were made to obtain good data on materials production etc. For the remaining processes, data were collected from literature and from the databases at CIT and IPU. The main data sources are presented in the next section.

Data quality assessment

The uncertainty, completeness and representativity of the data are discussed in the section on data quality assessment in each Technical report. These discussions take time-related and geographical aspects into account. Initially (Anon 1997), the aim was to state qualitatively for each data item the statistical uncertainty, the completeness (*e.g.,* whether data represent measurements over a month or a full year) and the representativity (*e.g.*, to what extent the data represent the process that should ideally be included in the assessment). To simplify the work, we focus on processes that contribute significantly to the total LCA results.

2.10 Data collection procedure

Making priorities

A screening analysis of the previous study was performed at the beginning of this project. This screening resulted in recommendations on which data were important to improve in the updating. The processes of the packaging systems were divided into four different priority groups (see Annex D):

- Priority 1: processes for which it is essential to obtain updated, specific data.
- Priority 2: processes for which updated, site specific data are important.
- Priority 3: processes for which improved data are important, but which may be based on literature data and models.
- Priority 4: processes for which data can be based on literature.

Data collection

A new data format was developed for this study, incorporating the requirements of the ISO standard with respect to the recording of data quality and types of data, as well as experiences from the work of SPOLD (1997). The format includes the data necessary to determine precision, completeness, and representativity of data. The data questionnaire that was sent out to data suppliers is based on previous questionnaires, which have been used by CIT and IPU, respectively. The questionnaire and instructions that were attached to it are found in Annex E.

The relevant data suppliers were asked in June 1997 if they were interested in participating in the study. The data questionnaire was distributed to most of these companies in July. Some of the companies referred to other companies or organisations such as the Association of Plastic Manufacturers in Europe (APME). The data received from the data suppliers arrived in the period August to December 1997. Additional data was collected in February 1998.

Data sources

The data received on glass and glass bottle production were site specific data from Holmegaard Glassworks (Eriksen 1997, Fought 1997), which dominates the Danish market for glass bottle production.

The data received on primary aluminium production represent an average for the European Aluminium Association (EAA 1996). New data on strip rolling were received directly from the EAA (de Gélas 1997). Data on aluminium can production were received from PLM (Nylin 1997). Data on aluminium recycling are site specific (confidential source).

Data on primary steel production and steel recycling were supplied by APEAL (Hatcher 1997). Data on steel can production were supplied by Schmalbach-Lubeca (Minet 1997).

The data received on PET and PET bottle production represent an average for the Association of Plastic Manufacturers in Europe (APME; Boustead 1995). Data on PET recycling were received from Wellman (Nichols 1997).

For the distribution we used data on actual transport distances and truck sizes (Jacobsen 1997). The fuel demand is based on data on the relevant vehicles from Volvo (Rydberg 1997). Most of the emissions are calculated using data from CORINAIR (1996). For further details, see Technical report 7.

For washing and filling, we received site specific data from breweries and soft drink producers.

The data on electricity production are presented and, in part, derived in Technical report 7.

Literature data were used on the production of materials for secondary and transport packagings, labels, coatings, NaOH etc.

Data validation

The collected data were validated at CIT and IPU. This validation included comparisons with other data sources and earlier experience. The data were further validated through a hearing round with the data suppliers (see section 2.15).

Data quality assessment

As indicated above, the representativity, uncertainty and completeness of the data are discussed in the sections on data quality assessment in Technical reports 1-7.

2.11 Impact assessment method

EDIP

The life cycle impact assessment method applied is the EDIP method (Wenzel *et al.* 1997). This method reflects the state of the art within life cycle impact assessment. As described below, it is consistent with ISO 14040 and the recommendations of the Society of Environmental Toxicology and Chemistry (SETAC).

Three elements

The EDIP method comprises three elements:

1. Calculation of potential environmental impacts of the systems - the question how much the emissions contribute to the various categories of environmental impacts is answered. More specifically, this element can be described as two subphases:

1a) associating inventory parameters with specific impact categories (*e.g.*, global warming), and
1b) calculation of the potential environmental impact for the different impact categories by multiplying the inventory data with substance- and group-specific impact potentials (*e.g.*, global warming potentials, GWP).

Compared to ISO 14040 and the SETAC "Code of Practice" (Consoli *et al.* 1993), the first subphase corresponds to classification. The second subphase corresponds to characterisation.

2. Normalisation - the question of how great the potential impacts on the environment and the working environment are, relative to the impact from society's activities as a whole, is answered. This means relating (by division) the calculated potential environmental impact from the investigated product system to the calculated total potential environmental impact from society's activities as a whole during a certain reference period for each impact category. In this way the relative contribution from the respective packaging systems to, *e.g.*, the total acidification during one year can be compared to the total acidification from society during the same year. The normalisation results are presented in the unit person equivalents (PE) or, more specifically, PE_{WDK90}. This unit refers to the (annual) environmental impact of an average person in Denmark or the world in 1990 (see Annex F).

3. Weighting - which of the potential impacts are the most important? In the EDIP method the weighting is based on political reduction targets. Together with the normalisation, this helps in assessing the relative importance of the product for the different impact categories. However, the weighting results are not aggregated into one index. They are presented separately for each impact category. This is an important aspect of the EDIP weighting method. In effect, the weighting factors are scale factors affecting all compared systems equally. The weighted results on resource depletion are presented in the unit person-reserve in 1990 (PR_{W90}). This unit refers to the known global reserves divided by the number of persons in the world in 1990. For other impact categories, the weighting results are presented in the unit person equivalents at target level (PET) or, more specifically, PET_{WDK90}. This unit refers to the (annual) environmental impact of an average person in Denmark or the world when, and if, the estimated target levels for the year 2000 are reached (see also Annex F).

In ISO 14040, the three steps classification, characterisation and weighting are suggested for impact assessment. The relation between this structure and the EDIP method is further clarified in Table 2.3.

Table 2.3
Relation between ISO 14040 definitions and the elements of the EDIP method.

Term according to ISO 14040	Step according to the EDIP method (see above)	Explanation
Classification	1a	Sorting of inventory parameters into impact categories
Characterisation	1b	Calculation of the potential contribution to the different impact categories from the studied life cycle
Weighting (formerly called valuation)	2+3	Assessment of the relative importance of the studied product system's potential contribution to the different categories

More recently, SETAC-Europe (Udo de Haes 1996) and the ISO committee draft 14042.2 (ISO 1997b) presented structures for impact assessment involving more than the three steps in ISO 14040. These structures explicitly includes the possibility of a normalisation step such as the one included in the EDIP method. An initial step including, *e.g.*, category selection is also added. This selection corresponds to the discussion on impact categories above.

Impact categories

Just like most other methods for life cycle impact assessment, the EDIP method studies potential environmental effects. A default list of relevant environmental impacts has been presented by SETAC-Europe (Udo de Haes 1996). The EDIP method covers most of these impacts (see Table 2.4). Besides the ones listed, the EDIP method allows inclusion of work environment impacts including bodily harm due to accidents.

The toxicological impacts are more disaggregated in Table 2.4 than in the SETAC-Europe default list. The reason is that the assessment of toxicological impacts can be improved by distinguishing between different compartments and exposure routes.

A difference compared to the SETAC-Europe default list is that we include waste flows as separate impact categories. The landfilling of the waste flows from the packaging systems is not included in the LCA. The reason is that the modelling of the landfills is not yet satisfactory. This means that the waste flows are recorded as non-elementary outflows from the systems, *i.e.*, flows not followed to the boundary between technosphere and nature.

Table 2.4
Environmental impact categories considered in the EDIP method.

Global warming (GWP)
Stratospheric ozone depletion (ODP)
Photochemical ozone formation (POCP)
Acidification (AP)
Nutrient enrichment (NP)
Human toxicological impacts:
- Human toxicity in the water compartment (HTW)
- Human toxicity in the air compartment (HTA)
- Human toxicity in the soil compartment (HTS)

Ecotoxicological impacts:
- Acute aquatic ecotoxicity (ETWA)
- Chronic aquatic ecotoxicity (ETWC)
- Chronic terrestrial ecotoxicity (ETSC)

Waste flows:
- Bulk waste (non-hazardous)
- Hazardous waste
- Slag and ashes
- Nuclear waste

Resource depletion (each resource is treated separately)

Omissions

The EDIP method does not currently include impacts from odour, noise, radiation, or littering in nature. Nor does it include land use related impacts. The noise may be a significant aspect of the packaging systems; especially the contribution from transportation (Kuemmel & Soerensen 1997). Furthermore, the EDIP method does not assess the environmental impacts related to biological and chemical oxygen demand (BOD and COD) caused by emissions to water.

As indicated above (section 2.2) work environment is not included in this study. The potential health effects of migration from the packaging to the beverage are also not included.

Insignificant results

Stratospheric ozone depletion was included in the study, but no emissions contributing significantly to this impact were recorded in the inventory analysis. This is consistent with the results from the previous study.

For all toxicity impacts and all ecotoxicological impacts, the results are included in the technical reports, but not in this main report. The reason is that no significant differences between the systems investigated were found. This is not because the toxicological impacts are similar in the various systems, but because the uncertainties are large.

In the base case scenario, the toxicological and ecotoxicological impacts via air and soil are dominated by emissions of non-methane volatile organic compounds (NMVOC) from the distribution and other transports. The potential human toxicity via water is dominated by Hg emissions from the combustion of coal, *e.g.*, at electricity production. The potential ecotoxicity impacts via water are dominated by emissions of Sr to water from coal extraction. There are large uncertainties and perhaps also significant data gaps, in particular in the Hg and Sr emissions (see sections 2.1 and 3.3 in Technical report 7).

The impact assessment method is further described in Annex F. For a complete description of this method, see Wenzel *et al.* (1997) and Hauschild & Wenzel (1998).

Compared to the previous study (Wesnæs 1996), we use a new set of characterisation factors for toxicity impacts. During the course of the project, new characterisation factors were also developed for a few compounds, such as COS (contributing to global warming) and HCN (contributing to acidification and nutrient enrichment).

The new toxicity factors are presented in Annex F. All characterisation factors, normalisation references and weighting factors used in this project are presented together with the impact assessment results in chapters 3-8 and in Technical reports 1-6.

2.12 Calculation procedure

Inventory analysis

The inventory calculations were carried out using the software LCA inventory Tool (LCAiT). Several hundred different parameters were used. To reduce the data volume, the emissions of non-methane volatile organic compounds (NMVOC) from electricity production were aggregated. The same was done for NMVOC emissions from diesel engines and from combustion of oil and natural gas. However, the disaggregated data were stored and used in the characterisation (see below). The data used in the inventory calculations are presented in LCAiT printouts in annexes to Technical reports 1-6.

For each process in LCAiT investigated, information is presented on the massflows to and from the process in the model. Emissions, primary resource demand, non-elementary inflows, co-products, and waste are reported. Furthermore, the energy carriers used in the process are reported. Below these data it is stated *e.g.*, that "the sum of the output flow(s) (13.791 kg) is used to calculate emissions and energies". This statement means that for this process the data on emissions, energy carriers etc. are presented per kg outflow and that, in the calculations, the data are multiplied by the total outflow (13.791 kg) to arrive at the total emissions etc. of that process.

Specific data on emissions from the combustion of a fuel were not available for all processes. When the system is solved, estimates for the combustion emissions are calculated through multiplying the fuel demand with emission factors for final use in the energy database (presented in annexes in Technical report 7). This calculation is reported through the use of the letters FU (final use) under the heading "E Factor" (emission factor).

In most cases, the process data do not include emissions etc. from the production of the electricity and fuels used in the process. These emissions etc. are calculated through multiplying the fuel or electricity demand by the corresponding emission factors for extraction etc. (see Technical report 7). This calculation is reported through the use of the letters Ex (extraction) under the heading "E Factor".

Data on transports are entered in a different structure in LCAiT. For each transport, data on transport modes and distances are presented. When the system is solved, the distances are multiplied by the total outflow to obtain the transport volume. For each transport mode, this volume is multiplied by the fuel demand data in the transport database (see Technical report 7). The emissions and resource demand are calculated through multiplying the fuel demand by the emission factors for fuel production and final use in the energy database.

The environmental inputs and outputs are calculated for each process and transport. The results are added to form the total inventory result for the system investigated.

Impact assessment

The impact assessment was carried out in Excel. Inventory results were multiplied by the EDIP characterisation factors to obtain characterisation results. In a few cases, new characterisation factors were developed to fit the parameters used in the inventory analysis. Characterisation factors were also calculated for the NMVOC mixes from electricity production, diesel engines and combustion of oil and natural gas. The characterisation factors used in the calculations are presented in the characterisation tables in chapters 3-8 and in Technical reports 1-6.

The characterisation results were divided by EDIP normalisation references to obtain normalisation results. The normalisation references are presented in the normalisation tables in chapters 3-8 and in Technical reports 1-6.

The normalisation results were multiplied by EDIP weighting factors to obtain weighting results. It should be noted that the weighting results are not aggregated into a single index, but presented for each separate impact category. The weighting factors are presented in the weighting tables in chapters 3-8 and in Technical reports 1-6.

2.13 Interpretation method

The conclusions of this project are based on the results of the LCA, a dominance analysis, a sensitivity analysis and an assessment of data gaps and data quality.

2.13.1 Dominance analysis

In the dominance analysis, the most serious environmental impacts and the largest resource depletions are identified. We also identify to what waste category the packaging systems contribute most.

The most important processes are identified for each environmental impact. Finally, the most important emissions for these important processes are identified.

2.13.2 Sensitivity analysis

The following aspects are considered in the sensitivity analysis:

- the recycling rates,
- the share of discarded glass and PET bottles at the brewery,
- the share of cullets in glass bottles,
- the weight of the primary packaging,
- the allocation methods,
- the electricity production,
- the share of virgin aluminium in the lid of steel and aluminium cans,
- transport data,
- the share of plastic crates discarded after use, and
- cut-offs and excluded parts of the product system

The sensitivity analyses are performed to investigate the consequences on the following emissions:

- CO_2, which is the most important compound for global warming,
- NO_x, which is important for acidification and nutrient enrichment,
- SO_2 which is important for acidification, and
- VOC, which is the most important group of compounds for photochemical ozone formation. NO_2

Some of these sensitivity analyses involved recalculations of the whole packaging system. Others are simplified, semi-quantitative sensitivity analyses or qualitative discussions (see Table 2.5). The results of the sensitivity analyses are presented in chapters 3-8 (see, *e.g.*, Table 3.14) and - in more detail - in section 5.2.4 in Technical reports 1-6. They are refered to in the comparisons between systems presented in chapters 10-14 (see, *e.g.*, section 10.3).

Table 2.5
Overview of the sensitivity analyses made in this study.

	Refillable glass bottle	Disposable glass bottle	Aluminium can	Steel can	Refillable PET bottle	Disposable PET bottle
Weight of the primary packaging	+20%	+20%	+20%	+ 20 %	+20%	+20%
The amount of coatings			qualitative	beer / soft drinks		
Allocation at recycling	qualitative	50/50	qualitative	50/50	qualitative	100% virg
Electricity production	fragmented markets & European baseload average	fragmented markets & European baseload average	fragmented markets, natural gas & European baseload average	fragmented markets, natural gas & European baseload average	fragmented markets & European baseload average	fragmented markets & European baseload average
Transport data	light truck distr.	qualitative	light truck distr.	light truck distr.	light truck distr.	light truck distr.
Collection rates	90%		98.5%		90%	
Share of cullets in glass bottles	qualitative	qualitative				
Share of recycled PET in bottles					qualitative	qualitative
Share of discarded bottles	qualitative				qualitative	
Cut-offs and other omissions	semi-quantitative	semi-quantitative	semi-quantitative	semi-quantitative	semi-quantitative	semi-quantitative

Heavier packagings

New calculations are made for all packagings with the assumption that the primary packaging is 20% heavier than in our data. It should be noted that the actual uncertainty in the packaging weights is less than 20%.

Coatings

Steel cans used for beer and soft drinks differ mainly in the amount of coatings. In the base case, an average amount of coatings was used. In the sensitivity analysis, new calculations are made based on the larger amount of coatings used in soft-drink steel cans. The results from these calculations illustrate the difference between beer and soft-drink steel cans. They also provide a sufficient basis for discussing the difference between beer and soft-drink aluminium cans.

Allocation

In the base case, we assume that recycled glass and steel from the packaging system will replace 100% virgin materials in other product systems (section 2.7.5). In the sensitivity analysis, new calculations are made on the disposable glass bottle system with the assumption that the glass recycled from the packaging system replaces 50% virgin raw material and 50% broken glass from other systems. Based on these results, the importance of this assumption on the refillable glass bottle system is discussed.

New calculations are also made on the steel can system with a similar assumption. This means that, *e.g.*, the steel recycled from the packaging system is assumed to replace 50% primary steel and 50% recycled steel from other systems.

In the base case, we assume that recycled PET from the packaging system replaces 50% virgin PET and 50% recycled PET from other systems (section 2.7.5). In the sensitivity analysis, new calculations are also made on the disposable PET bottle system with the assumption that the PET recycled from the packaging system replaces 100% primary material. Based on these results, the importance of this assumption on the refillable PET bottle system is discussed.

Electricity

The importance of the electricity production is assessed quantitatively for all systems. The emissions are recalculated two or three times, using data on:

- long-term base-load marginal electricity production under the assumption that the European market for electricity is fragmented (in Technical report 7, it is substantiated that the marginal technology in the Nordic countries would likely be based on natural gas, while the marginal technology in most other European countries is likely to be based on coal),
- electricity production based on 100% natural gas, and
- European base-load average.

The data on the different electricity sources are presented in Technical report 7. It should be noted that the actual uncertainty in the environmental impacts of the marginal electricity production is larger than what is reflected by this sensitivity analysis (see section 2.7.3).

Transport data

The environmental impacts of transports are in this LCA dominated by the impacts of the beverage distribution. The trucks used in the distribution are mainly medium-sized or large. In the sensitivity analysis, new calculations are made on all systems under the assumption that only light trucks are used for the distribution.

Collection rates

New calculations are made on the refillable glass and PET systems with the assumption that the collection rate is not 98.5% but 90%, *i.e.*, the same as the collection rate for the other systems. We also recalculated the results for 33 cl aluminium cans, assuming the collection rate to be 98.5% rather than 90%. This sensitivity analysis exaggerates the uncertainties in the collection rates. The collection rates for refillable glass and PET bottles in Denmark today are much higher than 90% (Jacobsen 1997).

The importance of the share of broken glass used in the glass bottle production is qualitatively discussed. A similar discussion is presented regarding the possible use of recycled PET in the production of PET bottles. These discussions were based, *e.g.*, on the results from the sensitivity analyses on recycling allocation and collection rates. These results are also used to discuss the importance of the rate of discarded bottles at washing and filling.

Cut-offs

ISO FDIS 14041 requires that decisions regarding what data to include in the LCA shall be based on a sensitivity analysis (ISO 1998). We believe that it is a reasonable interpretation to assume that the sensitivity analyses should be quantitative and cover all relevant environmental aspects, but the ISO document does not explicitly require this. It was not possible to carry through such comprehensive and detailed sensitivity analyses within the framework of this study. Instead, we make simplified, semi-quantitative sensitivity analyses where the magnitude of the cut-off flows is quantified and the environmental significance of the cut-offs is qualitatively discussed.

Sensitivity analyses were performed after initial calculations. As a result of these sensitivity analyses, it was decided to include the production of coatings for steel and aluminium cans and the production of NaOH used for the washing of refillable glass bottles.

Other omissions

As stated above, the environmental impacts of the production of secondary packagings and transport packagings are not included in the LCA - although the production of the main materials for these packagings is included. Neither are the environmental impacts of the retailer and the private transport home from the retailer included. In the sensitivity analysis, the effect on total energy demand of these omissions is calculated to be less than 1% each.

2.13.3 Assessment of data gaps and data quality

Data quality and data gaps are qualitatively discussed. The most important uncertainties in the inventory analysis and the impact assessment are identified and discussed.

2.13.4 Comparing the systems

The comparisons between the different packaging systems are presented in chapters 10-14. Before the comparisons are made, the comparability of the systems and analyses is discussed (see chapter 9).

The comparisons between the packaging systems are based on the energy demand and on the impact assessment results for the individual systems in the base-case scenario. The comparisons also take into account the most important uncertainties identified through the sensitivity analysis and the assessments of data gaps and data quality.

The comparisons are made separately for each environmental impact. The same conclusions are obtained regardless of whether the comparison is based on characterisation, normalisation or weighting results. The reason is that the normalisation references as well as the weighting factors are scale factors that affect all systems equally (see also chapter 9).

As indicated above (section 2.3), the functional unit in the comparisons is the average annual consumption of beer (or soft drinks) in Denmark 1993. These functional units are also scale factors that affect all systems equally. They do not affect the conclusions of the comparisons.

The comparisons include an explicit ranking of the compared packagings with respect to potential global warming, acidification, nutrient enrichment and photochemical ozone formation (see, *e.g.*, Table 10.9). The ranking involves an estimation of whether the differences between the packaging systems are significant or not. This estimation of significance is based on the base-case results and the most important uncertainties identified through the sensitivity analysis and the assessments of data gaps and data quality. It also takes into account the fact that the sensitivity analysis exaggerates the uncertainties in packaging weights and collection rates, while the actual uncertainty in electricity production is larger than what is reflected by the sensitivity analysis.

2.14 Reporting

The report series

As stated above, this report is one in a series of 8 from the LCA project. The reports in the series are listed and their content is briefly described in chapter 1, Introduction. The different packaging systems are described in Technical reports 1-6. These reports also include the data used in the calculations and the full results. The data on transports and energy production are presented in Technical report 7.

Structure of this report

Each of the following chapters (3-8) summarises the LCA of the packaging systems with one of the packaging types. All results in these chapters are dissaggregated into two figures:

- the environmental input/output of the processes in the packaging system itself, and
- the effects of the packaging system on the environmental input/output of other product systems.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems. Chapters 3-8 also summarises the dominance and sensitivity analyses that are made on the individual packaging systems.

Chapter 9 includes a discussion on the comparability of the different systems and analyses. Chapters 10-14 include the comparisons made in this project between packagings fulfilling similar use. Chapter 15, finally, includes the conclusions that can be drawn on a general level.

2.15 Critical review procedure

Critical review panel

An external independent expert was selected by the commissioner of the study to be chairperson of a critical review panel. The chairperson selected four other experts for the panel. The panel consists of:

- Allan Astrup Jensen, dk-TEKNIK, Denmark, chairperson
- Anders Schmidt, dk-TEKNIK, Denmark
- Dennis Postlethwaite, Merseyside, U.K.
- Ivo Fecker and Ruth Förster, EMPA, Switzerland

Hearing group

In addition to the critical review panel, a hearing group was formed. It consists of the data suppliers, and a few other organisations. The members of the hearing group are listed in Annex G.

Review rounds

The critical review procedure was carried out in three rounds. The hearing group was involved in the first two rounds:

1. after the preparation of a draft report of the pre-project,
2. after the LCAs of the individual packaging systems, and
3. after the preparation of a draft of the main report, comparing the individual packaging types.

The final report from the critical review panel is enclosed as Annex H. The response of the project group is enclosed as Annex I.

3 Refillable glass bottles

3.1 The systems

33 cl bottle

The process tree of the packaging systems is illustrated in Figure 3.1. The 33 cl refillable green glass bottle is produced from 17% virgin materials and 83% recycled glass from other systems. To distribute 1000 litres of beverage, 3030 glass bottles (1000/0.33) are needed. The weight of one 33 cl glass bottle is 300 grams.

25 cl bottle

The 25 cl refillable colourless glass bottle is produced from 54% virgin materials and 46% recycled glass from other systems. To distribute 1000 litres of beverage, 4000 glass bottles (1000/0.25) are needed. The weight of one 25 cl glass bottle is 240 grams. The process tree of the packaging system is illustrated in Figure 3.2.

Most of the used bottles (98.5%) are returned, washed and refilled. A small share of these bottles (1%) are accidentally crushed or discarded, and recycled into other systems (see Glass recycling above). The remaining 1.5% end up in waste management where they are incinerated, thereby consuming energy from other incinerated wastes (see Energy replaced).

3.2 Inventory analysis

3.2.1 33 cl refillable green glass bottle

Input data

The bottles, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 3.1. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 1. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

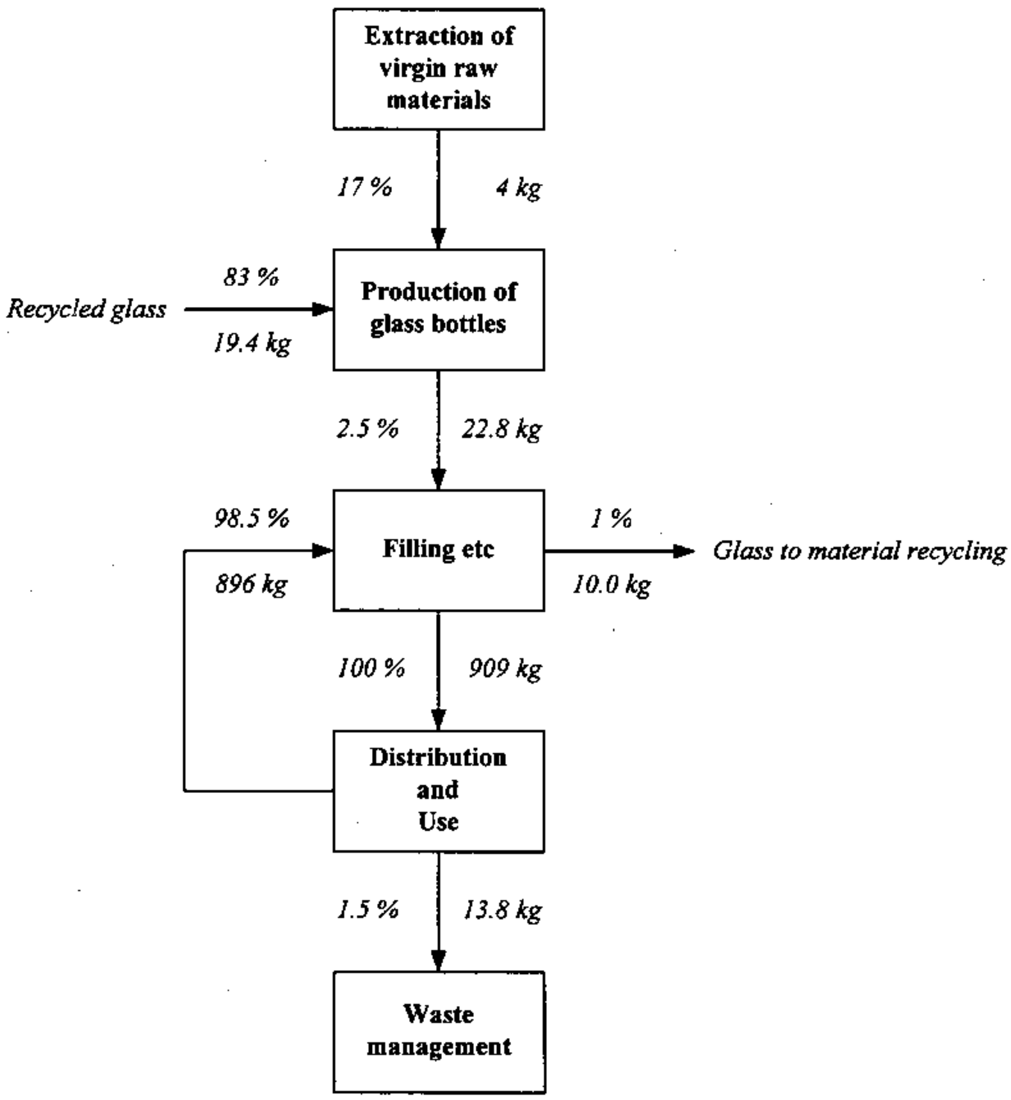

Figure 3.1
Flows of 33 cl refillable green glass bottle system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure. The mass balances do not add up due to material losses etc. which are not presented in the figure.

Table 3.1
System parameters for the packaging system with 33 cl refillable green glass bottles. The mass presented refers to the weight of a single item, i.e., one bottle or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of reuse	Material to recycling	Material to incineration
Primary packaging	Refillable glass bottle (33 cl)	300	100 %	Green glass	98.5 %	1.0 %	0.5 %
	Cap	2.02	100 %	Tinplate	0 %	2.9 %	97 %
	Cap-insert	0.19	100 %	LDPE	0 %	0 %	100 %
Label	Label	0.606	95 %	Paper	0 %	0 %	100 %
	Label and bottle neck	1.0	5 %	Aluminium	0 %	0 %	100 %
	Glue	0.2	100 %	Casein/urea/H_2O	0 %	0 %	100 %
Secondary packaging	Crates (30 bottles)	2140	90 %	HDPE	99.4 %	0.6 %	0 %
	Trays (54 bottles)	1662	10 %	HDPE	99.4 %	0.6 %	0 %
	Multipack (12 bottles)	170	1 %	Corrugated board	0 %	20 %	80 %
	Multipack (6 bottles)	17	8 %	Cardboard	0 %	20 %	80 %
	Multipack (6 bottles)	10	1 %	LDPE	0 %	20 %	80 %
Transport packaging	Pallet (900 bottles)	22000	100%	Wood	95%	0%	5%
	Plastic ligature (900 bottles)	20	100%	LDPE	0%	70%	30%

Energy demand

The energy demand of the system investigated are presented in Table 3.2. This table presents energy demand at final use - *i.e.*, the fuel and electricity used in the processes and transports of the systems investigated, not the energy resources extracted from nature. The energy demand caused by the packaging system is divided into two figures:

- the energy demand of the processes in the packaging system itself, and
- the effects of the packaging system on the energy demand of other product systems.

All results in this chapter are dissaggregated in this way. Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 3.2
Energy demand at final use for the packaging system with 33 cl refillable green glass bottles. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other life cycles	Total
Electricity, total	kWh	8,29E+01	-8,28E-01	8,20E+01
Electricity, coal marginal	*kWh*	*8,21E+01*	*-9,43E-01*	*8,12E+01*
Fossil fuel, total	MJ	1.40E+03	-8.58E+01	1.31E+03
Coal	*MJ*	*1.87E+01*	*5.91E-01*	*1.93E+01*
Diesel, heavy & medium truck (highway)	*MJ*	*1.26E+02*	*8.82E-02*	*1.26E+02*
Diesel, heavy & medium truck (rural)	*MJ*	*1.30E+02*	*8.08*	*1.38E+02*
Diesel, heavy & medium truck (urban)	*MJ*	*1.04E+02*	*6.65E-01*	*1.05E+02*
Hard coal, feedstock	*MJ*	*1.19E+02*	*0*	*1.19E+02*
Natural gas (>100 kW)	*MJ*	*6.70E+02*	*-5.12E+01*	*6.19E+02*
Natural gas	*MJ*	*1.29E+02*	*1.13E+01*	*1.40E+02*
Natural gas, feedstock	*MJ*	*2.35E+01*	*0*	*2.35E+01*
Oil	*MJ*	*1.33E+01*	*1.17*	*1.45E+01*
Oil, feedstock	*MJ*	*2.41E+01*	*0*	*2.41E+01*
Oil, heavy fuel	*MJ*	*1.36E+01*	*9.85E-01*	*1.46E+01*
Oil, light fuel	*MJ*	*8.35*	*-6.44E+01*	*-5.60E+01*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 3.3. Resources are here flows from the nature to the system investigated. The parameters used in Table 3.3 are the parameters used by the data suppliers and our other data sources. As an example, the table includes the parameters "brown coal" and "hard coal" as well as simply (unspecified) "coal". This is not a case of double counting, but a consequence of the fact that some data sources specify if the coal demand is brown coal or hard coal, while other sources do not specify this.

Table 3.3 also includes non-elementary inflows and outflows, *i.e.*, flows not followed to the boundary between technosphere and nature. The non-elementary inflows are ancillary materials and raw materials for which the production is excluded from the LCA. The non-elementary outflows include flows of waste for which the waste management is not included in the LCA. They also include co-products and recycled material which flow from the system investigated to other product systems.

The table presents a selection of the inventory results only. For a complete list, see Technical report 1.

Table 3.3

Selection of inventory results for the packaging system with 33 cl refillable green glass bottles. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Bauxite	g	2.44E+02	0	2.44E+02
Brown coal	g	6.17E+02	-2.41E+01	5.93E+02
Coal	g	6.70E+02	2.13E+01	6.91E+02
Crude oil	g	1.16E+04	-1.31E+03	1.03E+04
Crude oil, feedstock	g	5.95E+02	-4.05E-05	5.95E+02
Dolomite	g	3.22E+02	7.71E+02	1.09E+03
Feldspar	g	1.76E+02	4.22E+02	5.99E+02
Ground water	g	7.99E+03	-7.43E-06	7.99E+03
Hard coal	g	5.40E+04	-4.15E+02	5.36E+04
Hydro power-water	g	5.96E+09	6.16E+09	1.21E+10
Iron ore, 10% Fe	g	5.48E+04	0	5.48E+04
Land use	m^2•year	1.14E+02	4.35	1.18E+02
Limestone	g	2.62E+03	1.93E+03	4.55E+03
NaCl	g	2.37E+03	1.75E+03	4.12E+03
Natural gas	g	1.48E+04	-1.04E+03	1.38E+04
Natural gas, feedstock	g	4.34E+02	0	4.34E+02
Sand	g	2.32E+03	5.54E+03	7.86E+03
Softwood	g	1.52E+01	-1.05E-01	1.51E+01
Surface water	g	2.01E+05	-2.21E-07	2.01E+05
Tin	g	1.33E+01	0	1.33E+01
Water	g	1.33E+07	-1.26E+04	1.33E+07
Non-elementary inflows				
Alloys	g	3.16E+01	0	3.16E+01
Auxiliary materials	g	6.07E+01	1.76E+01	7.83E+01
Bark	g	4.33E+02	1.16E+01	4.45E+02
BF-additives	g	2.02E+02	0	2.02E+02
Binders	g	1.50E+02	0	1.50E+02
$Ca(OH)_2$	g	4.76E+02	0	4.76E+02
CaO	g	5.09E+01	1.97	5.29E+01
Coke	g	4.49E+01	0	4.49E+01

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	Unit	Packaging system	Effects on other product systems	Total
Corrugated board	g	5.80E+01	0	5.80E+01
Dry strength additives	g	6.36E+01	0	6.36E+01
Fillers	g	6.77E+02	0	6.77E+02
H_2SO_4	g	9.43E+01	3.17	9.74E+01
Ink	g	4.35E+01	0	4.35E+01
Lacquer, water	g	2.61E+01	0	2.61E+01
$NaClO_3$	g	8.65E+01	0	8.65E+01
NaOH	g	9.77E+01	1.76	9.94E+01
O_2	g	7.77E+01	0	7.77E+01
Oil	g	1.33E+01	0	1.33E+01
Other additives	g	1.55E+02	7.21E-02	1.55E+02
Peat	g	1.02E+02	1.26	1.04E+02
SO_2	g	6.09E+01	0	6.09E+01
Starch	g	2.89E+01	-5.94	2.30E+01
Steel scrap	g	7.46E+02	0	7.46E+02
Sulphur	g	2.50E+01	4.82E-02	2.51E+01
Urea	g	8.69E+01	-2.88E-02	8.69E+01
Emissions to air				
CH_4	g	4.61E+02	-1.37E+01	4.47E+02
CO	g	2.73E+02	1.06	2.74E+02
CO_2	g	1.69E+05	-6.98E+03	1.62E+05
HC	g	4.11E+01	3.23	4.43E+01
HCl	g	6.23	7.02E-02	6.30
NH_3	g	5.85E-01	1.19	1.78
NMVOC	g	7.74E+01	-1.08E+01	6.66E+01
NMVOC, diesel engines	g	4.12E+01	9.28E-01	4.22E+01
NMVOC, electricity-coal	g	1.37	-1.56E-02	1.36
NMVOC, natural gas combustion	g	5.82E-01	1.84E-03	5.84E-01
NMVOC, oil combustion	g	5.49	2.28E-01	5.71
NMVOC, power plants	g	7.75E-01	-5.27E-03	7.69E-01
NO_2	g	3.96E+01	3.25	4.28E+01
NO_x	g	6.16E+02	3.59	6.19E+02
Pentane	g	7.85E-01	-5.78E-02	7.27E-01
SO_2	g	2.49E+02	-1.63E-01	2.49E+02
VOC, diesel engines	g	1.13	-8.22E-03	1.13
Emissions to water				
Acid as H^+	g	7.87E-01	0	7.87E-01
BOD	g	1.46	1.85E-03	1.46
BOD-5	g	5.06	1.40	6.46

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	Unit	Packaging system	Effects on other product systems	Total
BOD-7	g	2.40E+01	0	2.40E+01
COD	g	1.99E+01	3.68	2.36E+01
Tot-N	g	3.11	-3.00E-01	2.81
Tot-P	g	2.17E-01	0	2.17E-01
Waste				
Bulk waste, total	g	6.33E+04	-2.87E+03	6.04E+04
Waste	*g*	*5.51E+03*	*0*	*5.51E+03*
Waste, bulky	*g*	*1.73E+04*	*-1.24E+02*	*1.71E+04*
Waste, industrial	*g*	*3.77E+04*	*-2.87E+03*	*3.49E+04*
Waste, mineral	*g*	*1.86E+02*	*3.43E+01*	*2.20E+02*
Waste, non-toxic	*g*	*1.23E+03*	*0*	*1.23E+03*
Waste, paper	*g*	*9.14E+02*	*0*	*9.14E+02*
Waste, paper production	*g*	*2.69E+02*	*0*	*2.69E+02*
Hazardous waste, total	g	5.58E+03	-3.80E+02	5.20E+03
Waste, hazardous	*g*	*5.57E+03*	*-3.80E+02*	*5.19E+03*
Slags & ashes, total	g	2.11E+04	-1.65E-01	2.11E+04
Waste, slags & ashes (energy prod.)	*g*	*4.14E+02*	*-4.34*	*4.10E+02*
Waste, slags & ashes	*g*	*2.07E+04*	*0*	*2.07E+04*
Nuclear waste, total	g	1.12E+01	9.84E-03	1.12E+01
Waste, highly radioactive	g	1.11E+01	1.03E-02	1.11E+01
Waste, radioactive	g	9.40E-02	-4.88E-04	9.35E-02
Co-products				
Aluminium	g	4.30E+01	0	4.30E+01
Benzene	g	2.21E+01	0	2.21E+01
Cardboard	g	6.78E+01	0	6.78E+01
Dust	g	3.80E+02	0	3.80E+02
Iron oxide	g	1.01E+01	0	1.01E+01
Iron(II)sulphate	g	1.04E+02	0	1.04E+02
LDPE	g	1.57E+01	0	1.57E+01
LDPE ligature	g	4.83E+01	0	4.83E+01
Mill scale	g	1.72E+02	0	1.72E+02
Paper, fuel	g	3.00E+02	0	3.00E+02
Paper, recycling	g	1.53E+02	0	1.53E+02
Slag	g	2.26E+03	0	2.26E+03
Tall oil	g	8.15E+01	0	8.15E+01
Tar	g	6.77E+01	0	6.77E+01
Tinplate	g	1.34E+02	0	1.34E+02

3.2.2 25 cl refillable colourless glass bottles

Input data

The bottle, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 3.4. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 1. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

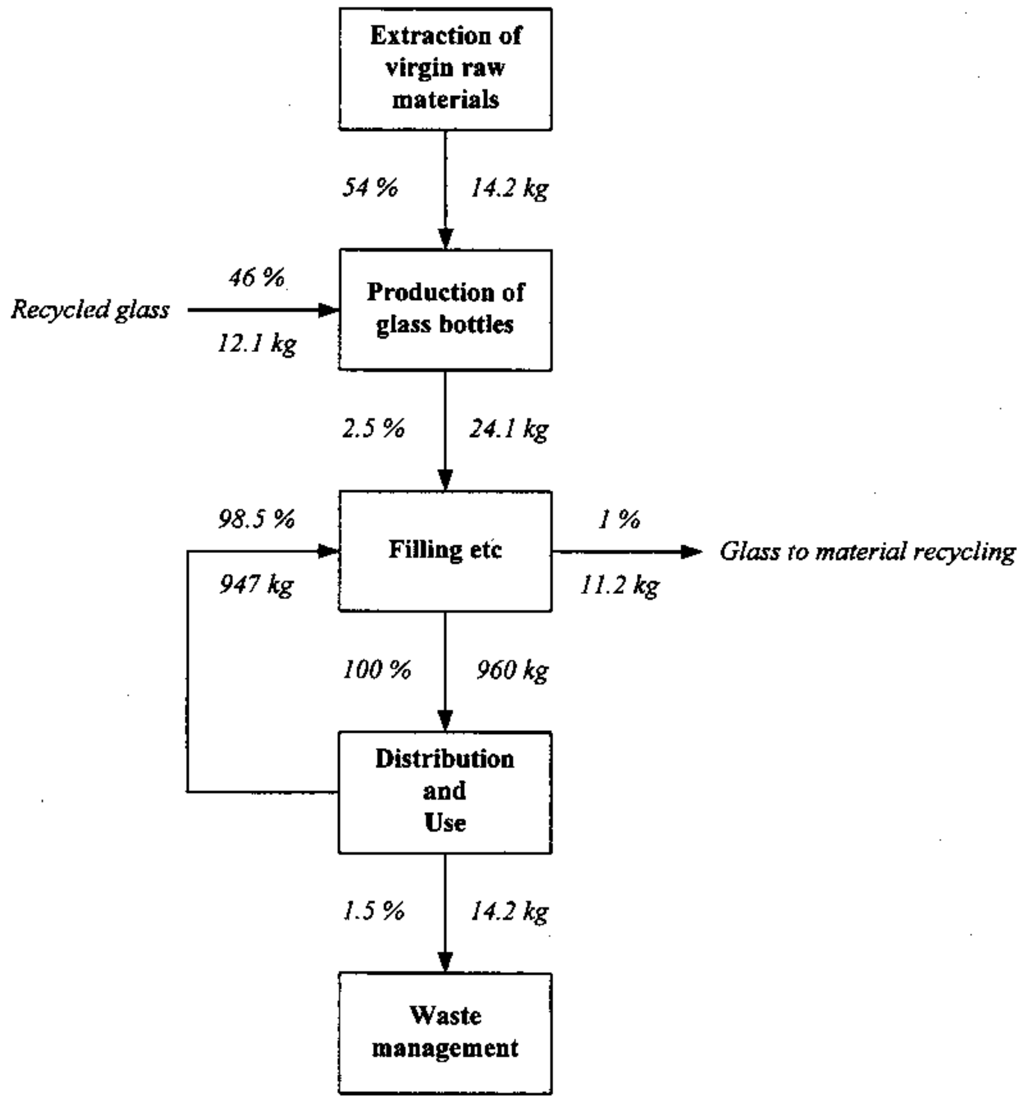

Figure 3.2

Process tree for the 25 cl refillable colourless glass bottle system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure. The mass balances do not add up due to material losses etc. which are not presented in the figure.

Table 3.4

System parameters for the packaging system with 25 cl refillable colourless glass bottles. The mass presented refers to the weight of a single item, i.e., one can or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of reuse	Material to recycling	Material to incineration
Primary packaging	Refillable glass bottle (25 cl)	240	100 %	White glass	97.5 %	1.0 %	1.5 %
	Cap	2.02	100 %	Tinplate	0 %	2.9 %	97 %
	Cap-insert	0.19	100 %	LDPE	0 %	0 %	100 %
Label	Label	0.606	100 %	Paper	0 %	0 %	100 %
	Glue	0.2	100 %	Casein/urea/H_2O	0 %	0 %	100 %
Secondary packaging	Crates (12 bottles)	950	10 %	HDPE	99.4 %	0.6 %	0 %
	Crates (24 bottles)	1350	20 %	HDPE	99.4 %	0.6 %	0 %
	Crates (30 bottles)	1700	70 %	HDPE	99.4 %	0.6 %	0 %
	Multipack (6 bottles)	17	10 %	Cardboard	0 %	0 %	100 %
Transport packaging	Pallet (900 bottles)	22000	100%	Wood	95%	0%	5%
	Plastic ligature (900 bottles)	20	100%	LDPE	0%	70%	30%

Energy demand

An explanation of the disaggregation made in Table 3.5 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 3.5

Energy demand at final use for the packaging system with 25 cl refillable colourless glass bottles. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	9.09E+01	-1.94	8.89E+01
Electricity, coal marginal	*kWh*	*9.01E+01*	*-1.96*	*8.82E+01*
Fossil fuel, total	MJ	1.63E+03	-1.51E+02	1.47E+03
Coal	*MJ*	*3.65E+01*	*5.00E-02*	*3.65E+01*
Diesel, heavy & medium truck (highway)	*MJ*	*1.35E+02*	*0*	*1.35E+02*
Diesel, heavy & medium truck (rural)	*MJ*	*1.43E+02*	*6.37*	*1.49E+02*
Diesel, heavy & medium truck (urban)	*MJ*	*1.21E+02*	*5.30E-02*	*1.21E+02*
Hard coal, feedstock	*MJ*	*1.58E+02*	*0*	*1.58E+02*
Natural gas (>100 kW)	*MJ*	*7.28E+02*	*-6.40E+01*	*6.64E+02*
Natural gas	*MJ*	*1.53E+02*	*1.02*	*1.54E+02*
Natural gas, feedstock	*MJ*	*2.88E+01*	*0*	*2.88E+01*
Oil	*MJ*	*2.54E+01*	*1.00E-01*	*2.55E+01*
Oil, feedstock	*MJ*	*2.96E+01*	*0*	*2.96E+01*
Oil, heavy fuel	*MJ*	*1.78E+01*	*5.30E-02*	*1.79E+01*
Oil, light fuel	*MJ*	*2.01E+01*	*-9.52E+01*	*-7.51E+01*
Oil	*MJ*	*2.54E+01*	*1.00E-01*	*2.55E+01*
Coal	*MJ*	*3.65E+01*	*5.00E-02*	*3.65E+01*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 3.6. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 1.

Table 3.6

Inventory results for the packaging system with 25 cl refillable colourless glass bottles. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Brown coal	g	7.04E+02	-4.55E+01	6.58E+02
Coal	g	1.30E+03	1.80	1.30E+03
Crude oil	g	1.35E+04	-2.31E+03	1.12E+04
Crude oil, feedstock	g	6.93E+02	-1.14E-04	6.93E+02
Dolomite	g	1.26E+03	8.00E+01	1.34E+03
Feldspar	g	7.84E+02	5.14E+01	8.35E+02
Ground water	g	7.53E+03	-2.34E-05	7.53E+03
Hard coal	g	6.10E+04	-1.14E+03	5.99E+04
Hydro power-water	g	1.09E+10	4.00E+07	1.09E+10
Iron ore, 10% Fe	g	7.23E+04	0	7.23E+04
Land use	m^2*year	1.51E+02	0	1.51E+02
Limestone	g	5.09E+03	1.70E+02	5.26E+03
NaCl	g	5.57E+03	1.40E+02	5.71E+03
Natural gas	g	1.64E+04	-1.42E+03	1.50E+04
Natural gas, feedstock	g	5.33E+02	0	5.33E+02
Sand	g	8.26E+03	5.40E+02	8.80E+03
Softwood	g	1.72E+01	-3.06E-01	1.69E+01
Surface water	g	2.64E+05	-6.23E-07	2.64E+05
Tin	g	1.76E+01	0	1.76E+01
Water	g	1.51E+07	-2.07E+05	1.49E+07
Wood	g	1.08E+01	-2.24	8.51
Non-elementary inflows				
Alloys	g	4.17E+01	0	4.17E+01
Auxiliary materials	g	1.36E+02	3.97	1.39E+02
Bark	g	5.73E+02	0	5.73E+02
BF-additives	g	2.67E+02	0	2.67E+02
Binders	g	1.97E+02	0	1.97E+02
$Ca(OH)_2$	g	5.51E+02	0	5.51E+02
CaO	g	6.77E+01	0	6.77E+01
Coke	g	5.93E+01	0	5.93E+01

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	Unit	Packaging system	Effects on other product systems	Total
Corrugated board	g	7.64E+01	0	7.64E+01
Dry strength additives	g	8.38E+01	0	8.38E+01
Fillers	g	8.92E+02	0	8.92E+02
H_2SO_4	g	1.25E+02	0	1.25E+02
Ink	g	5.73E+01	0	5.73E+01
Lacquer, various	g	1.15E+01	0	1.15E+01
Lacquer, water	g	3.44E+01	0	3.44E+01
$NaClO_3$	g	1.14E+02	0	1.14E+02
NaOH	g	1.29E+02	0	1.29E+02
O_2	g	1.02E+02	0	1.02E+02
Oil	g	1.75E+01	0	1.75E+01
Other additives	g	2.04E+02	0	2.04E+02
Peat	g	1.24E+02	0	1.24E+02
SO_2	g	8.01E+01	0	8.01E+01
Starch	g	2.58E+01	0	2.58E+01
Steel scrap	g	9.85E+02	0	9.85E+02
Sulphur	g	3.24E+01	0	3.24E+01
Urea	g	1.15E+02	0	1.15E+02
Emissions to air				
CH_4	g	5.23E+02	-1.77E+01	5.05E+02
CO	g	3.37E+02	-1.64	3.36E+02
CO_2	g	1.95E+05	-1.30E+04	1.82E+05
HC	g	6.71E+01	1.80E-01	6.73E+01
HCl	g	7.44	-1.35E-01	7.30
NH_3	g	1.64	1.00E-01	1.74
NMVOC	g	8.89E+01	-1.82E+01	7.06E+01
NMVOC, diesel engines	g	4.65E+01	4.90E-01	4.70E+01
NMVOC, electricity-coal	g	1.51	-3.26E-02	1.47
NMVOC, oil combustion	g	7.01	1.28E-02	7.02
NO_2	g	3.70E+01	2.62E-01	3.73E+01
NO_x	g	7.15E+02	-1.13E+01	7.03E+02
SO_2	g	3.13E+02	-1.05E+01	3.02E+02
Emissions to water				
Acid as H^+	g	1.57	0	1.57
BOD	g	1.83	3.54E-04	1.83
BOD-5	g	6.65	-1.04E-02	6.64
BOD-7	g	3.17E+01	0	3.17E+01
COD	g	2.54E+01	-3.41E-01	2.51E+01
Tot-N	g	3.72	-4.99E-01	3.22

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	Unit	Packaging system	Effects on other product systems	Total
Waste				
Bulk waste, total	g	7.09E+04	-4.08E+03	6.68E+04
Waste	*g*	*7.28E+03*	*0*	*7.28E+03*
Waste, bulky	*g*	*1.95E+04*	*-3.51E+02*	*1.92E+04*
Waste, industrial	*g*	*4.11E+04*	*-3.74E+03*	*3.74E+04*
Waste, mineral	*g*	*3.77E+02*	*2.86*	*3.80E+02*
Waste, non-toxic	*g*	*7.92E+02*	*0*	*7.92E+02*
Waste, paper	*g*	*1.20E+03*	*0*	*1.20E+03*
Waste, paper production	*g*	*3.54E+02*	*0*	*3.54E+02*
Hazardous waste, total	g	6.10E+03	-4.94E+02	5.60E+03
Waste, hazardous	*g*	*6.09E+03*	*-4.94E+02*	*5.59E+03*
Slags & ashes, total	g	2.36E+04	-9.32	2.36E+04
Waste, slags & ashes (energy prod.)	*g*	*4.58E+02*	*-9.55*	*4.48E+02*
Waste, slags & ashes	*g*	*2.31E+04*	*0*	*2.31E+04*
Nuclear waste, total	g	1.20E+01	-8.94E-03	1.20E+01
Waste, highly radioactive	*g*	*1.19E+01*	*-7.13E-03*	*1.19E+01*
Waste, radioactive	*g*	*1.07E-01*	*-1.81E-03*	*1.05E-01*
Co-products				
Benzene	g	2.92E+01	0	2.92E+01
Dust	g	5.02E+02	0	5.02E+02
Glue	g	4.59E+02	0	4.59E+02
Iron(II)sulphate	g	1.37E+02	0	1.37E+02
Iron oxide	g	1.34E+01	0	1.34E+01
LDPE	g	1.32E+01	0	1.32E+01
LDPE ligature	g	5.09E+01	0	5.09E+01
Mill scale	g	2.27E+02	0	2.27E+02
Paper, fuel	g	3.95E+02	0	3.95E+02
Paper, recycling	g	2.02E+02	0	2.02E+02
Slag	g	2.98E+03	0	2.98E+03
Tall oil	g	1.07E+02	0	1.07E+02
Tinplate	g	1.41E+02	0	1.41E+02

3.3 Impact assessment

This section presents results from the impact assessment of packaging systems with refillable glass bottles. The most important characterisation calculations and results are presented in Tables 3.7 and 3.8. For a full presentation of the classification and characterisation, we refer to Technical report 1.

Normalisation results are presented in Tables 3.9 and 3.10. Weighting results are presented in Tables 3.11 and 3.12.

Table 3.7

Classification and characterisation of the packaging system with 33 cl refillable green glass bottles. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NH_3	3.64E-03	2.13E-03	4.34E-03	6.47E-03
NO_2	1.35E-03	5.35E-02	4.38E-03	5.78E-02
NO_x	1.35E-03	8.31E-01	4.84E-03	8.36E-01
Emissions to water				
Tot-N	4.43E-03	1.38E-02	-1.33E-03	1.24E-02
Tot-P	3.20E-02	6.94E-03	0	6.94E-03
Total		**9.08E-01**	**1.21E-02**	**9.20E-01**

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Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	3.23E-03	-9.56E-05	3.13E-03
CO	3.00E-05	8.20E-03	3.17E-05	8.23E-03
HC	6.00E-04	2.46E-02	1.94E-03	2.66E-02
NMVOC	4.00E-04	3.10E-02	-4.32E-03	2.67E-02
NMVOC, diesel engines	6.00E-04	2.47E-02	5.57E-04	2.53E-02
NMVOC, electricity-coal	8.00E-04	1.10E-03	-1.25E-05	1.08E-03
NMVOC, natural gas combustion	4.00E-04	2.33E-04	7.36E-07	2.33E-04
NMVOC, oil combustion	3.00E-04	1.65E-03	6.85E-05	1.71E-03
NMVOC, power plants	5.00E-04	3.87E-04	-2.63E-06	3.85E-04
Pentane	4.00E-04	3.14E-04	-2.31E-05	2.91E-04
VOC, diesel engines	6.00E-04	6.81E-04	-4.93E-06	6.76E-04
Total		**9.64E-02**	**-1.92E-03**	**9.45E-02**

Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	5.48E-03	6.18E-05	5.54E-03
NH_3	1.88E-03	1.10E-03	2.24E-03	3.34E-03
NO_2	7.00E-04	2.77E-02	2.27E-03	3.00E-02
NO_x	7.00E-04	4.31E-01	2.51E-03	4.33E-01
SO_2	1.00E-03	2.49E-01	-1.63E-04	2.49E-01
Emissions to water				
Acid as H^+	3.20E-02	2.52E-02	0	2.52E-02
Total		**7.40E-01**	**6.97E-03**	**7.47E-01**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	1.15E+01	-3.41E-01	1.12E+01
CO_2	1.00E-03	1.69E+02	-6.98	1.62E+02
Total		**1.82E+02**	**-7.31**	**1.74E+02**

Table 3.8

Classification and characterisation of the packaging system with 25 cl refillable colourless glass bottles. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NO_2	1.35E-03	4.99E-02	3.52E-04	5.02E-02
NO_x	1.35E-03	9.63E-01	-1.53E-02	9.48E-01
Emissions to water				
Tot-N	4.43E-03	1.65E-02	-2.21E-03	1.43E-02
Total		**1.05**	**-1.69E-02**	**1.03**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	3.66E-03	-1.23E-04	3.53E-03
CO	3.00E-05	1.01E-02	-4.91E-05	1.01E-02
HC	6.00E-04	4.02E-02	1.08E-04	4.03E-02
NMVOC	4.00E-04	3.55E-02	-7.27E-03	2.82E-02
NMVOC, diesel engines	6.00E-04	2.79E-02	2.94E-04	2.82E-02
NMVOC, electricity-coal	8.00E-04	1.20E-03	-2.61E-05	1.18E-03
NMVOC, oil combustion	3.00E-04	2.10E-03	3.78E-06	2.10E-03
Total		**1.23E-01**	**-7.23E-03**	**1.16E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	6.54E-03	-1.18E-04	6.42E-03
NH_3	1.88E-03	3.08E-03	1.88E-04	3.27E-03
NO_2	7.00E-04	2.59E-02	1.83E-04	2.60E-02
NO_x	7.00E-04	5.00E-01	-7.91E-03	4.92E-01
SO_2	1.00E-03	3.12E-01	-1.05E-02	3.02E-01
Emissions to water				
Acid as H^+	3.20E-02	5.01E-02	0	5.01E-02
Total		**8.99E-01**	**-1.82E-02**	**8.81E-01**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	1.31E+01	-4.41E-01	1.26E+01
CO_2	1.00E-03	1.94E+02	-1.30E+01	1.81E+02
Total		**2.09E+02**	**-1.34E+01**	**1.95E+02**

Table 3.9

Normalisation results for the packaging system with 33 cl refillable green glass bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	2.09E-02	-8.40E-04	2.00E-02
Photochemical ozone formation (POCP)	20	4.82E-03	-9.59E-05	4.73E-03
Acidification (AP)	124	5.97E-03	5.62E-05	6.03E-03
Nutrient enrichment (NP)	298	3.05E-03	4.06E-05	3.09E-03
Waste				
Bulk waste (non-hazardous)	1350	4.69E-02	-2.13E-03	4.48E-02
Hazardous waste	20.7	2.70E-01	-1.84E-02	2.51E-01
Slag and ashes	320	6.04E-02	-4.71E-07	6.04E-02
Nuclear waste	0.159	7.04E-02	6.19E-05	7.05E-02
Resources				
Oil	590	2.06E-02	-2.22E-03	1.84E-02
Coal	570	5.87E-02	-4.23E-04	5.83E-02
Brown coal	250	2.47E-03	-9.62E-05	2.37E-03
Natural gas	310	4.93E-02	-3.35E-03	4.59E-02
Aluminium	3.1	1.98E-02	-1.43E-07	1.98E-02
Iron	100	5.48E-02	-4.99E-09	5.48E-02
Tin	0.04	3.32E-01	0	3.32E-01

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 3.10

Normalisation results for the packaging system with 25 cl refillable colourless glass bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	2,40E-02	-1,54E-03	2,24E-02
Photochemical ozone formation (POCP)	20	6,14E-03	-3,61E-04	5,78E-03
Acidification (AP)	124	7,25E-03	-1,47E-04	7,10E-03
Nutrient enrichment (NP)	298	3,51E-03	-5,68E-05	3,45E-03
Waste				
Bulk waste (non-hazardous)	1350	5,25E-02	-3,02E-03	4,94E-02
Hazardous waste	20.7	2,94E-01	-2,38E-02	2,70E-01
Slag and ashes	320	6,74E-02	-2,66E-05	6,74E-02
Nuclear waste	0.159	7,53E-02	7,54E-02	1,51E-01
Resources				
Oil	590	2,41E-02	-3,89E-03	2,02E-02
Coal	570	6,68E-02	-1,22E-03	6,56E-02
Brown coal	250	2,81E-03	-1,82E-04	2,63E-03
Natural gas	310	5,46E-02	-4,56E-03	5,01E-02
Iron	100	7,22E-02	-1,39E-08	7,22E-02
Tin	0.04	4,38E-01	0	4,38E-01

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 3.11

Weighting results for the packaging system with 33 cl refillable green glass bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	2.72E-02	-1.09E-03	2.61E-02
Photochemical ozone formation (POCP)	1.2	5.79E-03	-1.15E-04	5.67E-03
Acidification (AP)	1.3	7.76E-03	7.31E-05	7.84E-03
Nutrient enrichment (NP)	1.2	3.66E-03	4.87E-05	3.71E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	5.16E-02	-2.34E-03	4.92E-02
Hazardous waste	1.1	2.97E-01	-2.02E-02	2.76E-01
Slag and ashes	1.1	6.65E-02	-5.19E-07	6.65E-02
Nuclear waste	1.1	7.75E-02	6.81E-05	7.75E-02
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	4.74E-04	-5.10E-05	4.23E-04
Coal	5.80E-03	3.41E-04	-2.45E-06	3.38E-04
Natural gas	1.60E-02	7.88E-04	-5.36E-05	7.34E-04
Aluminium	5.10E-03	1.01E-04	-7.29E-10	1.01E-04
Iron	8.50E-03	4.66E-04	-4.24E-11	4.66E-04
Tin	3.70E-02	1.23E-02	0	1.23E-02

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

Table 3.12

Weighting results for the packaging system with 25 cl refillable colourless glass bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	3,12E-02	-2,01E-03	2,92E-02
Photochemical ozone formation (POCP)	1.2	7,37E-03	-4,34E-04	6,93E-03
Acidification (AP)	1.3	9,42E-03	-1,90E-04	9,23E-03
Nutrient enrichment (NP)	1.2	4,21E-03	-6,82E-05	4,14E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	5,77E-02	-3,32E-03	5,44E-02
Hazardous waste	1.1	3,23E-01	-2,62E-02	2,97E-01
Slag and ashes	1.1	7,41E-02	-2,92E-05	7,41E-02
Nuclear waste	1.1	8,29E-02	8,29E-02	1,66E-01
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	5,53E-04	-8,95E-05	4,64E-04
Coal	5.80E-03	3,87E-04	-7,09E-06	3,80E-04
Natural gas	1.60E-02	8,74E-04	-7,30E-05	8,01E-04
Iron	8.50E-03	6,14E-04	-1,18E-10	6,14E-04
Tin	3.70E-02	1,62E-02	0	1,62E-02

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

3.4 Interpretation

Important impacts

The packaging systems with disposable glass bottles contribute most to the global warming potential (see Tables 3.9-3.12).

Waste and resources

The refillable glass bottle systems contribute considerably (>100 mPET) to the generation of hazardous waste. They also contribute significantly (>1 mPR) to the depletion of tin resources.

Important processes

The most important processes for the environmental impacts of the 33 cl refillable green glass bottle system are presented in Table 3.13.

Table 3.13
The most important processes of the 33 cl refillable green glass bottle system. The figures are given in % of the net total potential environmental impact.

	GWP	POCP	AP	NP
1. Bottle production .			11	
5. Washing and filling	50		24	22
6. NaOH production		12		
16. Tinplate production	11			
60. Distribution	17	56	30	41

Washing and filling

The process of washing and filling the bottles is the largest contributor to the global warming potential, caused by emissions of CO_2. This process is also a large contributor to the following impact categories:

- acidification potential, caused by the emissions of NO_x, and SO_2, and
- nutrification potential, caused by the emissions of NO_x

Distribution

The distribution is the largest contributor to the following impact categories:

- nutrification potential, caused by emissions of NO_x,
- acidification potential, caused by the emissions of NO_x and SO_2, and
- photochemical ozone formation, caused by general emissions of NMVOC and NMVOC from diesel engines

Waste generation

The hazardous waste is generated at the brewery (washing and filling).

Resource demand

Tin resources are used in the production of caps.

Sensitivity analyses

Sensitivity analyses were carried out as described in section 2.13. The quantitative results are presented in Table 3.14.

Table 3.14
Results from the quantitative sensitivity analyses made on the packaging system with 33 cl refillable green bottles. Functional unit: packaging and distribution of 1000 litres.

Parameters	Base case [g/1000 l beverage]	90 % collection rate [% of base case]	Bottle weight (+ 20 %) [% of base case]	Distribution (light truck) [% of base case]	Electricity, fragmented markets [% of base case]	Electricity, European base load [% of base case]
CO_2	1.62E+05	146	115	121	86	82
SO_2	2.49E+02	183	112	115	80	178
NO_x	6.62E+02	163	112	149	85	89
VOC. total	6.13E+02	138	112	124	48	63

Collection rate

The collection rate is 98.5 % in the base case. A sensivity analysis where the collection rate was decreased from 98.5 % (as in the base case) to 90 % was performed. The results for some of the important inventory parameters are shown in Table 3.14. It is clear from the results that the assumption regarding the collection rate is important.

Bottle weight

The bottle weight is 300 g in the base case. This could be compared to 325 g in the previous study. A sensitivity analysis where the bottle weight was increased by 20 % (to 360 g) was performed. The results for some of the important inventory parameters are shown in Table 3.14. The bottle weight appears to be of minor importance especially since a bottle weight increase of 20 % is an exaggeration.

Distribution of beverage

The bottles are distributed by medium and heavy trucks in the base case. A sensitivity analysis using data for distribution by light truck showed that the choice of truck influences the results, especially concerning NO_x (Table 3.14).

Electricity production

The electricity data used in the base case represent coal marginal. Three sensitivity analyses were performed for electricity production (long term baseload at fragmented markets, natural gas marginal and European baseload average). It is clear from the results (Table 3.14) that the assumption regarding the electricity production is important.

It should be noted that the large decrease in VOC for these scenarios is almost entirely due to the decrease in CH_4 emissions. Discounting the emissions of CH_4, the total VOC does not change noticeably.

Discarded bottles

An increased share of dicarded bottles at the brewery (the share of discarded bottles is 1 % in the base case) has similar effects as the decrease of the collection rate above.

Allocation methods

In the base case all of the discarded glass bottles are asssumed to replace virgin raw materials in other products. This assumption is of little importance for the LCA results of refillable glass bottles.

Data gaps and omissions

The most important data gap is that we have had no information about the actual water emissions in the washing and filling process.

The analysis did not include the production of a large number of ancillary materials.

Production of materials for secondary packagings (multipacks), transport packaging (pallets and plastic ligature) and cap inserts is included in the LCA, but the actual packaging production - conversion, nailing etc. - is not included.

The analysis does not include the environmental impacts of the retailer, nor the private transport to and from the retailer. These omissions affect the total energy demand of the system by approximately 1 % and 0.5 % respectively.

Uncertainties

The data quality for the two most important processes (distribution and washing & filling) are assessed to have a medium uncertainty, fair completeness and good representativity.

The uncertainties in the normalisation of toxicity impacts are large. However, this does not affect the comparisons between the systems.

For further details, see Technical report 1.

4 Disposable glass bottles

4.1 The systems

Green bottle

The process tree of the packaging systems is illustrated in Figure 4.1. The 33 cl disposable green glass bottle is produced from 17% virgin materials and 83% recycled glass from other systems. To distribute 1000 litres of beverage, 3030 glass bottles (1000/0.33) are needed. The weight of one green glass bottle is 145 grams.

Colourless bottle

The process tree of the packaging system is illustrated in Figure 4.2. The 33 cl disposable colourless glass bottle is produced from 54% virgin materials and 46% recycled glass from other systems. The weight of one colourless glass bottle is 145 grams.

Most of the used bottles (90%) are recycled into other products. The remaining 10% end up in waste management where they are incinerated, thereby consuming energy from other incinerated wastes (see Energy replaced).

4.2 Inventory analysis

4.2.1 33 cl disposable green glass bottle

Input data

The bottles, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 4.1. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 2. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

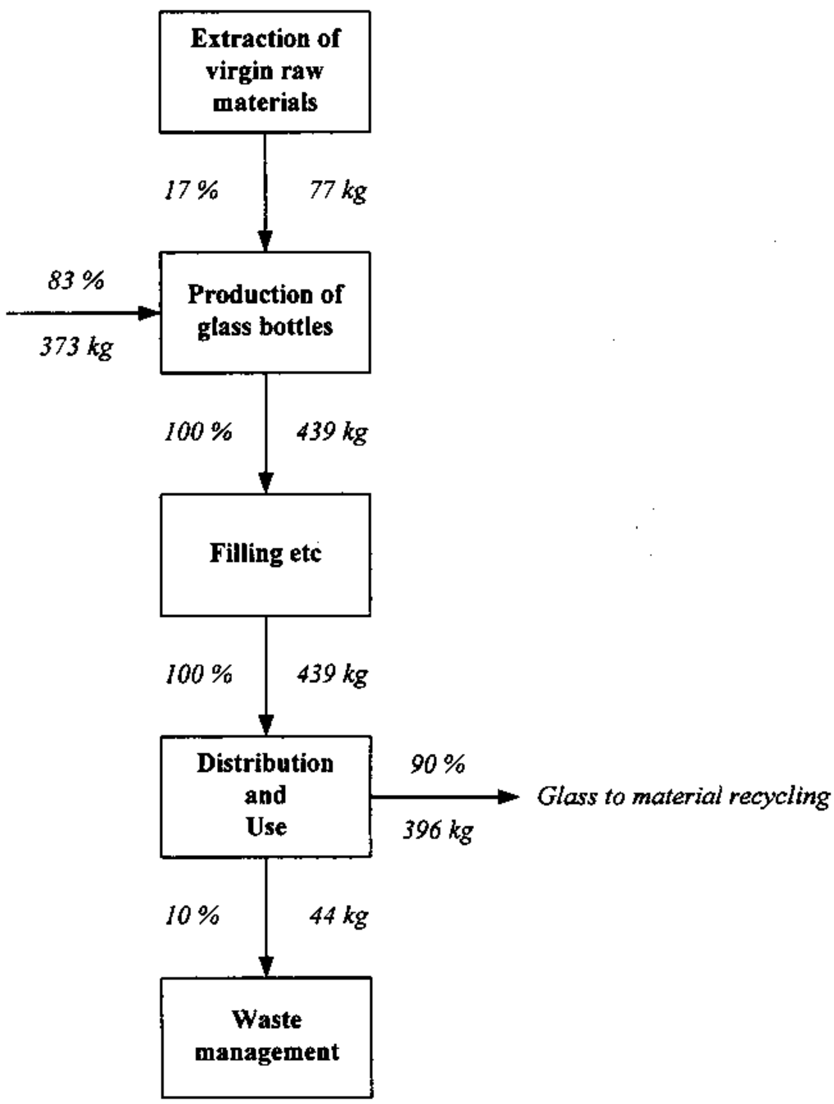

Figure 4.1
Flows of 33 cl disposable green glass bottles for beer per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure. The mass balances do not add up due to material losses etc. which are not presented in the figure.

Table 4.1
System parameters for the packaging system with 33 cl disposable green glass bottles. The mass presented refers to the weight of a single item, i.e., one bottle or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of reuse	Material to recycling	Material to incineration
Primary packaging	Disposable green glass bottle (33 cl)	145	100 %	Green glass	0	90 %	10 %
	Cap	2.02	100 %	Tinplate	0 %	2.9 %	97 %
	Cap-insert	0.19	100 %	LDPE	0 %	0 %	100 %
Label	Label	0.606	95 %	Paper	0 %	0 %	100 %
	Label and bottle neck	0.7	5 %	Aluminium	0 %	0 %	100 %
	Glue	0.2	100 %	Casein/urea/H_2O	0 %	0 %	100 %
Secondary packaging	Tray (24 bottles)	130	50 %	Corrugated board	0 %	20 %	80 %
	Foil for cardboard (24 bottles)	20	33 %	LDPE	0 %	0 %	100 %
	Box (24 bottles)	280	17 %	Corrugated board	0 %	20 %	80 %
	Wraparound (6 bottles)	70	10 %	Cardboard	0 %	20 %	80 %
Transport packaging	Pallet (900 bottles)	22000	100%	Wood	95%	0%	5%
	Plastic ligature (900 bottles)	20	75%	LDPE	0%	70%	30%
	Glue	2	25%	Casein/urea/H_2O	0%	0%	100%

Energy demand

An explanation of the disaggregation made in Table 4.2 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 4.2
Energy demand at final use for the packaging system with 33 cl disposable green glass bottles. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	1.67E+02	5.89E-02	1.67E+02
Electricity. coal marginal	*kWh*	*1.65E+02*	*2.97E-01*	*1.65E+02*
Fossil fuel, total	MJ	3.11E+03	-2.09E+02	2.90E+03
Diesel, heavy & medium truck (highway)	*MJ*	*9.68E+01*	*2.91*	*9.98E+01*
Diesel, heavy & medium truck (rural)	*MJ*	*1.63E+02*	*2.10E+02*	*3.73E+02*
Diesel, heavy & medium truck (urban)	*MJ*	*9.67E+01*	*4.77*	*1.01E+02*
Diesel, ship (4-stroke)	*MJ*	*3.19E+01*	*8.01*	*3.99E+01*
Hard coal	*MJ*	*2.53E+01*	*-6.28*	*1.90E+01*
Hard coal, feedstock	*MJ*	*1.19E+02*	*0*	*1.19E+02*
LPG, forklift	*MJ*	*1.35E+01*	*-2.38E-01*	*1.33E+01*
Natural gas (<100 kW)	*MJ*	*1.34E+01*	*-3.02*	*1.04E+01*
Natural gas	*MJ*	*2.08E+03*	*-3.22E+01*	*2.05E+03*
Natural gas, feedstock	*MJ*	*4.93E+01*	*0*	*4.93E+01*
Oil	*MJ*	*1.52E+01*	*-2.95*	*1.23E+01*
Oil, feedstock	*MJ*	*5.05E+01*	*0*	*5.05E+01*
Oil, heavy fuel	*MJ*	*4.83E+01*	*1.50E+01*	*6.33E+01*
Oil, light fuel	*MJ*	*1.04E+02*	*-2.20E+02*	*-1.16E+02*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 4.3. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 2.

Table 4.3

Selection of inventory results for the packaging system with 33 cl disposable green glass bottles. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Bauxite	g	5.70E+01	0	5.70E+01
Brown coal	g	1.09E+03	9.73	1.10E+03
Coal	g	3.47E+02	-5.32E+01	2.94E+02
Crude oil	g	1.69E+04	5.15E+02	1.74E+04
Crude oil, feedstock	g	1.19E+03	-1.86E-05	1.19E+03
Dolomite	g	6.21E+03	-1.90E+03	4.31E+03
Feldspar	g	3.40E+03	-1.10E+03	2.30E+03
Ground water	g	1.54E+05	2.95E-04	1.54E+05
Hard coal	g	1.02E+05	-2.36E+02	1.02E+05
Hydro power-water	g	3.13E+10	1.17E+11	1.49E+11
Iron ore, 10% Fe	g	5.46E+04	0	5.46E+04
Land use	m^2•year	2.42E+02	1.44E+02	3.85E+02
Limestone	g	1.73E+04	-4.80E+03	1.25E+04
NaCl	g	1.41E+04	-4.40E+03	9.71E+03
Natural gas	g	5.40E+03	-4.00E+03	1.39E+03
Natural gas, feedstock	g	9.11E+02	0	9.11E+02
Sand	g	4.47E+04	-1.40E+04	3.07E+04
Softwood	g	2.87E+01	-6.57E-02	2.86E+01
Surface water	g	2.00E+05	-1.19E-07	2.00E+05
Tin	g	1.33E+01	0	1.33E+01
Water	g	2.08E+07	-1.08E+05	2.07E+07
Wood	g	1.25E+01	1.43E-01	1.26E+01
Non-elementary inflows				
Alloys	g	3.15E+01	0	3.15E+01
Alum	g	2.61E+01	2.94E+01	5.55E+01
Auxiliary materials	g	8.45E+02	-4.38E+01	8.01E+02
Bark	g	7.92E+02	3.83E+02	1.17E+03
BF-additives	g	2.02E+02	0	2.02E+02
Binders	g	1.50E+02	0	1.50E+02
$Ca(OH)_2$	g	1.26E+03	0	1.26E+03

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	Unit	Packaging system	Effects on other product systems	Total
$CaCO_3$	g	2.19E+01	2.46E+01	4.65E+01
CaO	g	1.02E+02	6.51E+01	1.68E+02
Coke	g	4.48E+01	0	4.48E+01
Corrugated board	g	5.79E+01	0	5.79E+01
Defoamer	g	1.01E+01	8.74	1.88E+01
Dry strength additives	g	6.35E+01	0	6.35E+01
Fillers	g	6.76E+02	0	6.76E+02
H_2SO_4	g	1.77E+02	1.05E+02	2.82E+02
Ink	g	4.34E+01	0	4.34E+01
Lacquer, water	g	2.61E+01	0	2.61E+01
Na_2SO_4	g	3.46E+01	3.89E+01	7.35E+01
$NaClO_3$	g	8.64E+01	0	8.64E+01
Na_2CO_3	g	1.66E+01	1.35E+01	3.01E+01
NaOH	g	1.60E+02	5.80E+01	2.18E+02
NH_3	g	1.57E+01	0	1.57E+01
O_2	g	7.76E+01	0	7.76E+01
Oil	g	1.32E+01	0	1.32E+01
Other additives	g	1.74E+02	2.38	1.76E+02
Peat	g	4.08E+02	4.16E+01	4.50E+02
Retention agents	g	1.81E+01	1.35E+01	3.16E+01
Sizing agents	g	5.92E+01	2.06E+01	7.99E+01
SO_2	g	6.23E+01	0	6.23E+01
Starch	g	3.46E+02	-1.96E+02	1.49E+02
Steel scrap	g	7.44E+02	0	7.44E+02
Sulphur	g	4.08E+01	1.59	4.24E+01
Urea	g	9.70E+01	-9.53E-01	9.61E+01
Emissions to air				
CH_4	g	8.44E+02	-1.79E+02	6.65E+02
CO	g	3.83E+02	4.41E+01	4.27E+02
CO_2	g	3.51E+05	-1.33E+04	3.38E+05
HC	g	6.87E+01	-8.17	6.05E+01
HCl	g	1.23E+01	-3.46E-01	1.20E+01
NH_3	g	9.72	-2.95	6.77
NMVOC	g	1.01E+02	9.03E-01	1.02E+02
NMVOC, diesel engines	g	4.41E+01	1.85E+01	6.26E+01
NMVOC, electricity-coal	g	2.75	5.03E-03	2.75
NMVOC, natural gas combustion	g	1.12E+01	-5.70E-03	1.12E+01
NMVOC, oil combustion	g	1.64E+01	3.41	1.98E+01
NO_2	g	7.64E+02	-8.09	7.56E+02

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	Unit	Packaging system	Effects on other product systems	Total
NO_x	g	9.05E+02	1.50E+02	1.06E+03
SO_2	g	9.53E+02	-7.22	9.45E+02
VOC, diesel engines	g	2.15	-4.40E-03	2.15
Emissions to water				
BOD	g	6.45	-4.54E-03	6.45
BOD-5	g	5.14E+01	4.65E+01	9.79E+01
BOD-7	g	2.40E+01	0	2.40E+01
COD	g	1.64E+02	1.28E+02	2.92E+02
Tot-N	g	4.21	-1.63E-01	4.05
Waste				
Bulk waste, total	g	7.69E+04	-1.01E+04	6.68E+04
Elementary waste, corrugated board	*g*	*0*	*-9.68E+02*	*-9.68E+02*
Waste	*g*	*5.50E+03*	*0*	*5.50E+03*
Waste, bulky	*g*	*3.25E+04*	*-2.92E+01*	*3.25E+04*
Waste, $CaCO_3$	*g*	*1.69E+02*	*-5.22E+01*	*1.16E+02*
Waste, industrial	*g*	*1.23E+04*	*-1.02E+04*	*2.11E+03*
Waste, inert	*g*	*2.72E+02*	*1.35E+03*	*1.62E+03*
Waste, inorganic sludges	*g*	*1.19E+02*	*1.25E+02*	*2.44E+02*
Waste, mineral	*g*	*3.18E+02*	*-8.79E+01*	*2.30E+02*
Waste, non-toxic	*g*	*2.38E+04*	*0*	*2.38E+04*
Waste, other rejects	*g*	*3.60E+02*	*-1.42E+02*	*2.17E+02*
Waste, paper	*g*	*9.12E+02*	*0*	*9.12E+02*
Waste, paper production	*g*	*2.69E+02*	*0*	*2.69E+02*
Waste, solid	*g*	*1.86E+02*	*-5.75E+01*	*1.28E+02*
Hazardous waste, total	g	2.47E+03	-1.42E+03	1.04E+03
Waste, chemical	*g*	*2.66E+01*	*2.31E-04*	*2.66E+01*
Waste, hazardous	*g*	*2.42E+03*	*-1.42E+03*	*9.98E+02*
Waste, oil and fat	*g*	*1.23E+01*	*0*	*1.23E+01*
Slags & ashes, total	g	5.20E+04	4.00E+01	5.21E+04
Waste, ashes	*g*	*1.06E+02*	*3.91E+01*	*1.46E+02*
Waste, slags & ashes (energy prod.)	*g*	*8.20E+02*	*8.26E-01*	*8.21E+02*
Waste, slags & ashes	*g*	*5.11E+04*	*0*	*5.11E+04*
Nuclear waste, total	g	8.80	2.38E-01	9.04
Waste, highly radioactive	*g*	*8.62*	*2.37E-01*	*8.86*
Waste, radioactive	*g*	*1.81E-01*	*1.53E-03*	*1.82E-01*

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	Unit	Packaging system	Effects on other product systems	Total
Co-products				
Benzene	g	2.21E+01	0	2.21E+01
Biogas	g	0	-9.10E+01	-9.10E+01
Cardboard	g	1.08E+02	0	1.08E+02
Corrugated board	g	1.44E+03	0	1.44E+03
Dust	g	3.79E+02	0	3.79E+02
Glue	g	4.57E+01	0	4.57E+01
Iron(II)sulphate	g	1.03E+02	0	1.03E+02
Iron oxide	g	1.01E+01	0	1.01E+01
LDPE ligature	g	2.40E+01	0	2.40E+01
Mill scale	g	1.72E+02	0	1.72E+02
Paper, fuel	g	3.00E+02	0	3.00E+02
Paper, recycling	g	1.53E+02	0	1.53E+02
Slag	g	2.25E+03	0	2.25E+03
Tall oil	g	8.14E+01	0	8.14E+01
Tar	g	6.75E+01	0	6.75E+01
Tinplate	g	9.32E+01	0	9.32E+01

Input data

4.2.2 33 cl disposable colourless glass bottle

The bottle, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 4.4. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 2. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

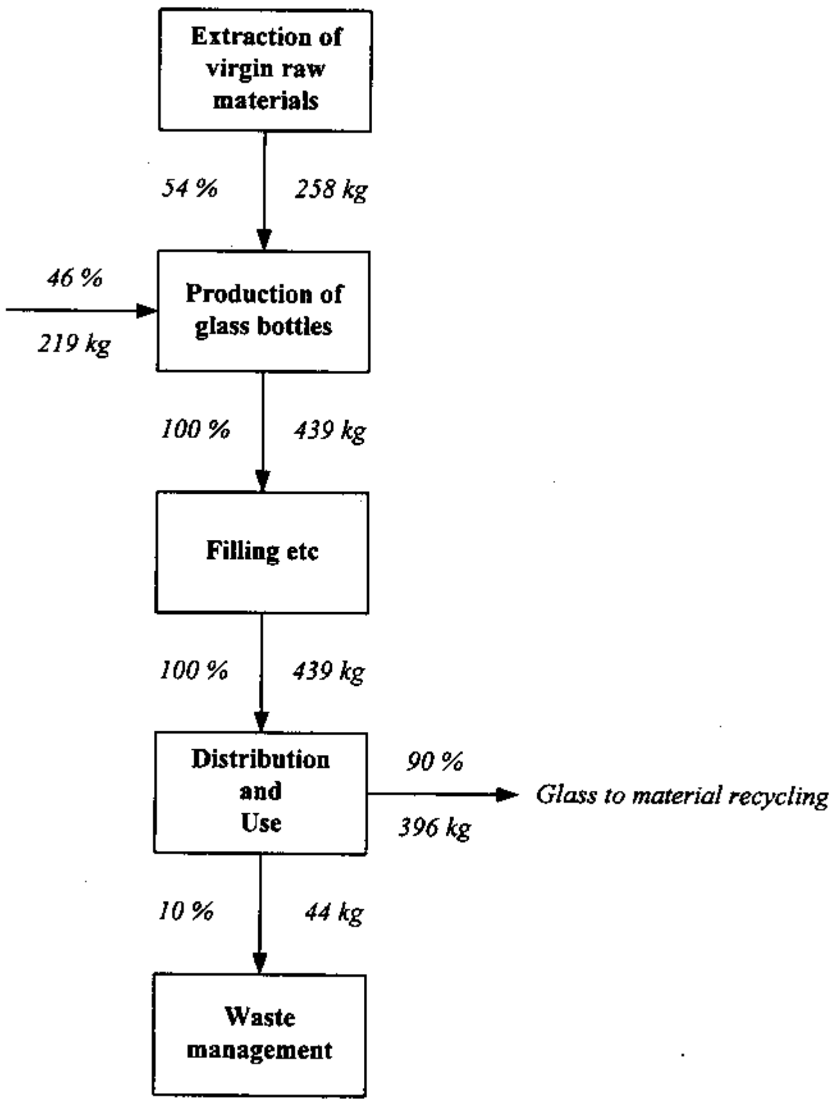

Figure 4.2
Flows of 33 cl disposable colourless glass bottles for soft drinks per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure. The mass balances do not add up due to material losses etc. which are not presented in the figure.

Table 4.4
System parameters for the packaging system with 33 cl disposable colourless glass bottles. The mass presented refers to the weight of a single item, i.e., one can or one tray. The market shares of the secondary packaging does not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of reuse	Material to recycling	Material to incineration
Primary packaging	Disposable colourless glass bottle (33 cl)	145	100 %	Colourless glass	0	90 %	10 %
	Cap	2.02	100 %	Tinplate	0 %	2.9 %	97 %
	Cap-insert	0.19	100 %	LDPE	0 %	0 %	100 %
Label	Label	0.606	100 %	Paper	0 %	0 %	100 %
	Glue	0.2	100 %	Casein/urea/H_2O	0 %	0 %	100 %
Secondary packaging	Tray (24 bottles)	130	50 %	Corrugated board	0 %	20 %	80 %
	Foil for cardboard (24 bottles)	20	33 %	LDPE	0 %	0 %	100 %
	Box (24 bottles)	280	17 %	Corrugated board	0 %	20 %	80 %
	Wraparound (6 bottles)	70	10 %	Cardboard	0 %	20 %	80 %
Transport packaging	Pallet (900 bottles)	22000	100%	Wood	95%	0%	5%
	Plastic ligature (900 bottles)	20	75%	LDPE	0%	70%	30%
	Glue	2	25%	Casein/urea/H_2O	0%	0%	100%

Energy demand

An explanation of the disaggregation made in Table 4.5 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 4.5
Energy demand at final use for the packaging system with 33 cl disposable colourless glass bottles. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	1.42E+02	-7.55	1.34E+02
Electricity, coal marginal	*kWh*	*1.38E+02*	*-5.89*	*1.33E+02*
Fossil fuel, total	MJ	3.49E+03	-7.55E+02	2.74E+03
Diesel, heavy & medium truck (highway)	*MJ*	*9.68E+01*	*2.91*	*9.97E+01*
Diesel, heavy & medium truck (rural)	*MJ*	*1.64E+02*	*1.68E+02*	*3.31E+02*
Diesel, heavy & medium truck (urban)	*MJ*	*1.07E+02*	*-4.89*	*1.02E+02*
Diesel, ship (4-stroke)	*MJ*	*8.42E+01*	*-4.04E+01*	*4.38E+01*
Hard coal	*MJ*	*6.37E+01*	*-4.39E+01*	*1.99E+01*
Hard coal, feedstock	*MJ*	*1.19E+02*	*0*	*1.19E+02*
LPG, forklift	*MJ*	*1.35E+01*	*-2.38E-01*	*1.33E+01*
Natural gas (<100 kW)	*MJ*	*3.26E+01*	*-2.15E+01*	*1.11E+01*
Natural gas	*MJ*	*2.11E+03*	*-2.07E+02*	*1.91E+03*
Natural gas, feedstock	*MJ*	*4.93E+01*	*0*	*4.93E+01*
Oil	*MJ*	*3.32E+01*	*-2.07E+01*	*1.25E+01*
Oil, feedstock	*MJ*	*5.05E+01*	*0*	*5.05E+01*
Oil, heavy fuel	*MJ*	*5.90E+01*	*5.21*	*6.42E+01*
Oil, light fuel	*MJ*	*2.94E+02*	*-3.97E+02*	*-1.03E+02*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 4.6. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 2.

Table 4.6

Selection of inventory results for the packaging system with 33 cl disposable colourless glass bottles. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Brown coal	g	1.10E+03	-1.60E+02	9.44E+02
Coal	g	6.74E+02	-3.73E+02	3.01E+02
Crude oil	g	2.39E+04	-7.39E+03	1.65E+04
Crude oil, feedstock	g	1.18E+03	-6.03E-04	1.18E+03
Dolomite	g	2.30E+04	-1.71E+04	5.90E+03
Feldspar	g	1.43E+04	-1.06E+04	3.70E+03
Ground water	g	1.37E+05	1.63E-04	1.37E+05
Hard coal	g	8.98E+04	-6.07E+03	8.37E+04
Hydro power-water	g	8.90E+10	-7.01E+10	1.89E+10
Iron ore, 10% Fe	g	5.46E+04	0	5.46E+04
Land use	m^2•year	2.42E+02	1.44E+02	3.85E+02
Limestone	g	5.09E+04	-3.67E+04	1.42E+04
NaCl	g	4.09E+04	-3.05E+04	1.04E+04
Natural gas	g	6.86E+03	-5.46E+03	1.40E+03
Natural gas, feedstock	g	9.11E+02	0	9.11E+02
Sand	g	1.50E+05	-1.12E+05	3.80E+04
Softwood	g	2.52E+01	-1.72	2.35E+01
Surface water	g	2.00E+05	-3.25E-06	2.00E+05
Tin	g	1.33E+01	0	1.33E+01
Water	g	1.94E+07	-2.19E+06	1.72E+07
Wood	g	1.89E+01	-6.88	1.20E+01
Non-elementary inflows				
Alloys	g	3.15E+01	0	3.15E+01
Alum	g	2.61E+01	2.94E+01	5.55E+01
Auxiliary materials	g	2.06E+03	-8.20E+02	1.24E+03
Bark	g	7.92E+02	3.83E+02	1.17E+03
BF-additives	g	2.02E+02	0	2.02E+02
Binders	g	1.50E+02	0	1.50E+02
$Ca(OH)_2$	g	1.26E+03	0	1.26E+03
$CaCO_3$	g	2.19E+01	2.46E+01	4.65E+01

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	Unit	Packaging system	Effects on other product systems	Total
CaO	g	1.02E+02	6.51E+01	1.68E+02
Coke	g	4.48E+01	0	4.48E+01
Corrugated board	g	5.79E+01	0	5.79E+01
Defoamer	g	1.01E+01	8.74	1.88E+01
Dry strength additives	g	6.35E+01	0	6.35E+01
Fillers	g	6.76E+02	0	6.76E+02
H_2SO_4	g	1.77E+02	1.05E+02	2.82E+02
Ink	g	4.34E+01	0	4.34E+01
Lacquer, water	g	2.61E+01	0	2.61E+01
Na_2SO_4	g	3.46E+01	3.89E+01	7.35E+01
$NaClO_3$	g	8.64E+01	0	8.64E+01
Na_2CO_3	g	1.66E+01	1.35E+01	3.01E+01
NaOH	g	1.60E+02	5.80E+01	2.18E+02
NH_3	g	1.57E+01	0	1.57E+01
O_2	g	7.76E+01	0	7.76E+01
Oil	g	1.32E+01	0	1.32E+01
Other additives	g	1.74E+02	2.38	1.76E+02
Peat	g	4.08E+02	4.16E+01	4.50E+02
Retention agents	g	1.81E+01	1.35E+01	3.16E+01
Sizing agents	g	5.92E+01	2.06E+01	7.99E+01
SO_2	g	6.23E+01	0	6.23E+01
Starch	g	3.46E+02	-1.96E+02	1.49E+02
Steel scrap	g	7.44E+02	0	7.44E+02
Sulphur	g	4.08E+01	1.59	4.24E+01
Urea	g	9.70E+01	-9.53E-01	9.61E+01
Emissions to air				
CH_4	g	7.78E+02	-2.55E+02	5.24E+02
CO	g	4.85E+02	1.54	4.86E+02
CO_2	g	3.91E+05	-6.57E+04	3.25E+05
HC	g	1.18E+02	-5.76E+01	6.01E+01
HCl	g	1.29E+01	-2.96	9.95
NH_3	g	2.82E+01	-2.08E+01	7.32
NMVOC	g	1.53E+02	-5.58E+01	9.77E+01
NMVOC, diesel engines	g	4.82E+01	1.05E+01	5.87E+01
NMVOC, electricity-coal	g	2.31	-9.80E-02	2.22
NMVOC, natural gas combustion	g	1.13E+01	-4.41E-02	1.12E+01
NMVOC, oil combustion	g	1.88E+01	1.15	2.00E+01
NO_2	g	6.73E+02	-5.41E+01	6.19E+02
NO_x	g	9.98E+02	-3.87E+01	9.59E+02

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	Unit	Packaging system	Effects on other product systems	Total
SO_2	g	1.11E+03	-1.40E+02	9.74E+02
VOC, natural gas combustion	g	5.32E-09	-3.44E-10	4.97E-09
Emissions to water				
BOD	g	5.99	-3.56E-02	5.96
BOD-5	g	5.14E+01	4.65E+01	9.79E+01
BOD-7	g	2.40E+01	0	2.40E+01
COD	g	1.65E+02	1.27E+02	2.92E+02
Tot-N	g	5.67	-1.76	3.92
Waste				
Bulk waste, total	g	6.74E+04	-1.72E+04	5.02E+04
Elementary waste, corrugated board	*g*	*0*	*-9.68E+02*	*-9.68E+02*
Waste	*g*	*5.50E+03*	*0*	*5.50E+03*
Waste, bulky	*g*	*2.86E+04*	*-1.90E+03*	*2.67E+04*
Waste, $CaCO_3$	*g*	*4.90E+02*	*-3.66E+02*	*1.24E+02*
Waste, industrial	*g*	*1.41E+04*	*-1.20E+04*	*2.03E+03*
Waste, inert	*g*	*1.14E+03*	*-8.50E+02*	*2.90E+02*
Waste, inorganic sludges	*g*	*1.19E+02*	*1.25E+02*	*2.44E+02*
Waste, mineral	*g*	*8.44E+02*	*-6.04E+02*	*2.40E+02*
Waste, non-toxic	*g*	*1.44E+04*	*0*	*1.44E+04*
Waste, other rejects	*g*	*3.60E+02*	*-1.42E+02*	*2.17E+02*
Waste, paper	*g*	*9.12E+02*	*0*	*9.12E+02*
Waste, paper production	*g*	*2.69E+02*	*0*	*2.69E+02*
Waste, solid	*g*	*5.39E+02*	*-4.03E+02*	*1.37E+02*
Hazardous waste, total	g	2.49E+03	-1.62E+03	8.70E+02
Waste, chemical	*g*	*2.35E+01*	*-7.47E-03*	*2.35E+01*
Waste, hazardous	*g*	*2.45E+03*	*-1.62E+03*	*8.31E+02*
Waste, oil and fat	*g*	*1.10E+01*	*0*	*1.10E+01*
Slags & ashes, total	g	5.20E+04	-3.56E+01	5.19E+04
Waste, ashes	*g*	*1.49E+02*	*-2.39*	*1.47E+02*
Waste, slags & ashes (energy prod.)	*g*	*6.96E+02*	*-3.32E+01*	*6.63E+02*
Waste, slags & ashes	*g*	*5.11E+04*	*0*	*5.11E+04*
Nuclear waste, total	g	8.91	9.66E-02	9.01
Waste, highly radioactive	*g*	*8.75*	*1.06E-01*	*8.86*
Waste, radioactive	*g*	*1.62E-01*	*-9.17E-03*	*1.52E-01*

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	Unit	Packaging system	Effects on other product systems	Total
Co-products				
Benzene	g	2.21E+01	0	2.21E+01
Biogas	g	0	-9.10E+01	-9.10E+01
Cardboard	g	1.08E+02	0	1.08E+02
Corrugated board	g	1.44E+03	0	1.44E+03
Dust	g	3.79E+02	0	3.79E+02
Iron(II)sulphate	g	1.03E+02	0	1.03E+02
Iron oxide	g	1.01E+01	0	1.01E+01
LDPE ligature	g	2.40E+01	0	2.40E+01
Mill scale	g	1.72E+02	0	1.72E+02
Paper, fuel	g	3.00E+02	0	3.00E+02
Paper, recycling	g	1.53E+02	0	1.53E+02
Slag	g	2.25E+03	0	2.25E+03
Tall oil	g	8.14E+01	0	8.14E+01
Tar	g	6.75E+01	0	6.75E+01
Tinplate	g	9.32E+01	0	9.32E+01

4.3 Impact assessment

This section presents results from the impact assessment of packaging systems with disposable glass bottles. The most important characterisation calculations and results are presented in Tables 4.7 and 4.8. For a full presentation of the classification and characterisation, we refer to Technical report 2.

Normalisation results are presented in Tables 4.9 and 4.10. Weighting results are presented in Tables 4.11 and 4.12.

Table 4.7

Classification and characterisation of the packaging system with 33 cl disposable green glass bottles. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NH_3	3.64E-03	3.54E-02	-1.07E-02	2.47E-02
NO_2	1.35E-03	1.03	-1.09E-02	1.02
NO_x	1.35E-03	1.22	2.03E-01	1.42
Emissions to water				
Tot-N	4.43E-03	1.86E-02	-7.23E-04	1.79E-02
Total		**2.32**	**1.80E-01**	**2.50**

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Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	5.91E-03	-1.25E-03	4.65E-03
CO	3.00E-05	1.15E-02	1.32E-03	1.28E-02
HC	6.00E-04	4.12E-02	-4.90E-03	3.63E-02
NMVOC	4.00E-04	4.06E-02	3.61E-04	4.09E-02
NMVOC, diesel engines	6.00E-04	2.64E-02	1.11E-02	3.75E-02
NMVOC, electricity-coal	8.00E-04	2.20E-03	4.02E-06	2.20E-03
NMVOC, natural gas combustion	4.00E-04	4.49E-03	-2.28E-06	4.49E-03
NMVOC, oil combustion	3.00E-04	4.91E-03	1.02E-03	5.94E-03
VOC, diesel engines	6.00E-04	1.29E-03	-2.64E-06	1.29E-03
Total		**1.40E-01**	**7.32E-03**	**1.47E-01**

Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	1.08E-02	-3.05E-04	1.05E-02
NH_3	1.88E-03	1.83E-02	-5.54E-03	1.27E-02
NO_2	7.00E-04	5.35E-01	-5.67E-03	5.29E-01
NO_x	7.00E-04	6.34E-01	1.05E-01	7.39E-01
SO_2	1.00E-03	9.53E-01	-7.22E-03	9.45E-01
Total		**2.16**	**8.81E-02**	**2.24**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	2.11E+01	-4.48	1.66E+01
CO_2	1.00E-03	3.51E+02	-1.33E+01	3.38E+02
Total		**3.74E+02**	**-1.75E+01**	**3.56E+02**

Table 4.8
Classification and characterisation of the packaging system with 33 cl disposable colourless glass bottles. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NH_3	3.64E-03	1.03E-01	-7.59E-02	2.67E-02
NO_2	1.35E-03	9.08E-01	-7.31E-02	8.35E-01
NO_x	1.35E-03	1.35	-5.22E-02	1.29
Emissions to water				
Tot-N	4.43E-03	2.51E-02	-7.78E-03	1.74E-02
Total		**2.39**	**-2.10E-01**	**2.18**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	5.45E-03	-1.78E-03	3.67E-03
CO	3.00E-05	1.45E-02	4.62E-05	1.46E-02
HC	6.00E-04	7.06E-02	-3.46E-02	3.61E-02
NMVOC	4.00E-04	6.14E-02	-2.23E-02	3.91E-02
NMVOC, diesel engines	6.00E-04	2.89E-02	6.30E-03	3.52E-02
NMVOC, electricity-coal	8.00E-04	1.85E-03	-7.84E-05	1.77E-03
NMVOC, natural gas combustion	4.00E-04	4.51E-03	-1.76E-05	4.49E-03
NMVOC, oil combustion	3.00E-04	5.65E-03	3.46E-04	5.99E-03
VOC, diesel engines	6.00E-04	1.13E-03	-7.46E-05	1.06E-03
Total		**1.95E-01**	**-5.29E-02**	**1.43E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NH_3	1.88E-03	5.29E-02	-3.92E-02	1.38E-02
NO_2	7.00E-04	4.71E-01	-3.79E-02	4.33E-01
NO_x	7.00E-04	6.98E-01	-2.71E-02	6.71E-01
SO_2	1.00E-03	1.11	-1.40E-01	9.74E-01
Total		**2.35**	**-2.45E-01**	**2.11**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	1.95E+01	-6.37	1.31E+01
CO_2	1.00E-03	3.91E+02	-6.57E+01	3.25E+02
Total		**4.12E+02**	**-7.22E+01**	**3.40E+02**

Table 4.9
Normalisation results for the packaging system with 33 cl disposable green glass bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	4.30E-02	-2.02E-03	4.10E-02
Photochemical ozone formation (POCP)	20	6.98E-03	3.66E-04	7.35E-03
Acidification (AP)	124	1.74E-02	7.10E-04	1.81E-02
Nutrient enrichment (NP)	298	7.77E-03	6.02E-04	8.38E-03
Waste				
Bulk waste (non-hazardous)	1350	5.69E-02	-7.47E-03	4.95E-02
Hazardous waste	20.7	1.19E-01	-6.88E-02	5.03E-02
Slag and ashes	320	1.49E-01	1.14E-04	1.49E-01
Nuclear waste	0.159	5.53E-02	1.50E-03	5.68E-02
Resources				
Oil	590	3.06E-02	8.72E-04	3.15E-02
Coal	570	1.10E-01	-3.11E-04	1.10E-01
Brown coal	250	4.38E-03	3.89E-05	4.42E-03
Natural gas	310	2.04E-02	-1.29E-02	7.44E-03
Aluminium	3.1	4.66E-03	1.66E-08	4.66E-03
Iron	100	5.46E-02	-3.09E-09	5.46E-02
Tin	0.04	3.31E-01	0	3.31E-01

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 4.10
Normalisation results for the packaging system with 33 cl disposable colourless glass bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	4,74E-02	-8,30E-03	3,91E-02
Photochemical ozone formation (POCP)	20	9,77E-03	-2,65E-03	7,13E-03
Acidification (AP)	124	1,90E-02	-1,98E-03	1,70E-02
Nutrient enrichment (NP)	298	8,03E-03	-7,06E-04	7,33E-03
Waste				
Bulk waste (non-hazardous)	1350	4,98E-02	-1,28E-02	3,70E-02
Hazardous waste	20.7	1,20E-01	-7,83E-02	4,18E-02
Slag and ashes	320	1,48E-01	-1,02E-04	1,48E-01
Nuclear waste	0.159	5,60E-02	6,08E-04	5,67E-02
Resources				
Oil	590	4,25E-02	-1,25E-02	2,99E-02
Coal	570	9,65E-02	-6,91E-03	8,96E-02
Brown coal	250	4,40E-03	-6,39E-04	3,76E-03
Natural gas	310	2,51E-02	-1,76E-02	7,44E-03
Iron	100	5,46E-02	-7,21E-08	5,46E-02
Tin	0.04	3,31E-01	0	3,31E-01

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 4.11

Weighting results for the packaging system with 33 cl disposable green glass bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	5,59E-02	-2,62E-03	5,32E-02
Photochemical ozone formation (POCP)	1.2	8,38E-03	4,39E-04	8,82E-03
Acidification (AP)	1.3	2,26E-02	9,23E-04	2,35E-02
Nutrient enrichment (NP)	1.2	9,33E-03	7,23E-04	1,01E-02
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	6,26E-02	-8,22E-03	5,44E-02
Hazardous waste	1.1	1,31E-01	-7,57E-02	5,53E-02
Slag and ashes	1.1	1,64E-01	1,26E-04	1,64E-01
Nuclear waste	1.1	6,09E-02	1,65E-03	6,25E-02
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	7,04E-04	2,01E-05	7,25E-04
Coal	5.80E-03	6,39E-04	-1,80E-06	6,37E-04
Brown coal	2.60E-03	1,14E-05	1,01E-07	1,15E-05
Natural gas	1.60E-02	3,26E-04	-2,07E-04	1,19E-04
Aluminium	5.10E-03	2,38E-05	8,44E-11	2,38E-05
Iron	8.50E-03	4,64E-04	-2,62E-11	4,64E-04
Tin	3.70E-02	1,23E-02	0	1,23E-02

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve. *i.e.*, the fraction of known global reserves per person, in 1990.

Table 4.12

Weighting results for the packaging system with 33 cl disposable colourless glass bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	6,16E-02	-1,08E-02	5,08E-02
Photochemical ozone formation (POCP)	1.2	1,17E-02	-3,17E-03	8,56E-03
Acidification (AP)	1.3	2,47E-02	-2,57E-03	2,21E-02
Nutrient enrichment (NP)	1.2	9,64E-03	-8,47E-04	8,79E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	5,48E-02	-1,40E-02	4,07E-02
Hazardous waste	1.1	1,32E-01	-8,61E-02	4,60E-02
Slag and ashes	1.1	1,63E-01	-1,12E-04	1,63E-01
Nuclear waste	1.1	6,16E-02	6,68E-04	6,23E-02
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	9,77E-04	-2,88E-04	6,89E-04
Coal	5.80E-03	5,60E-04	-4,01E-05	5,20E-04
Natural gas	1.60E-02	4,01E-04	-2,82E-04	1,19E-04
Iron	8.50E-03	4,64E-04	-6,13E-10	4,64E-04
Tin	3.70E-02	1,23E-02	0	1,23E-02

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve. *i.e.*, the fraction of known global reserves per person, in 1990.

4.4 Interpretation

The analyses and interpretations below are made for the green glass bottle, but represents the colourless bottle also, since the two systems are almost identical.

Important impacts

The packaging systems with disposable glass bottles contribute most to the following environmental impacts (see Tables 4.9-4.12):

- the global warming potential, and
- the acidification potential.

Waste and resources

The disposable glass bottle systems contribute conciderably (>100 mPET) to the generation of slags & ashes. They also contribute significantly (>1 mPR) to the depletion of tin resources.

Important processes

The most important processes for the environmental impacts of the 33 cl disposable green glass bottle system are presented in Table 4.13.

Table 4.13
The most important processes of the 33 cl disposable green glass bottle system. The figures are given in % of the net total potential environmental impact.

	GWP	POCP	AP	NP
1. Bottle production	73	16	68	58
2. Recycled glass from other systems	36	101	37	39
3. Virgin raw glass materials		18		
48. Distribution		25		10
53. Trp. Bottles		10		
54. Recycled glass bottles	64	14	59	50
56. Virgin glass bottles (avoided)	-100	-112	-95	-87

Bottle production

The production of bottles is a large contributor to the following impact categories:

- global warming potential, caused by emissions of CO_2
- acidification potential, caused by emissions of SO_2, NO_2 and NOx, and
- nutrification potential, caused by emissions of NO_2, NOx

Recycled glass from other systems

The use of recycled glass from other systems is a large contributor to the following categories:

- global warming potential, caused by CO_2 emissions
- photchemical ozon formation, caused by emissions of HC, NMVOC from diesel engines and general NMVOC to air
- acidification potential, caused by emissions of SO_2, NOx and NO_2, and
- nutrification potential, caused by emissions of NOx, NO_2 and NH_3

Distribution

The distribution is the largest contributor to the chronical ecotoxicity, soil, caused by its large emissions of NMVOC from diesel engines to air. This process is also a large contributor to the photochemical ozone formation, caused by general emissions of NMVOC and NMVOC from diesel engines to air.

Recycled glass bottles

The production of bottles based on recycled glass is a large contributor to the following impact categories:

- global warming potential, caused by emissions of CO_2
- acidification potential, caused by emissions of SO_2, NO_2 and NOx, and
- nutrification potential, caused by emissions of NO_2,NOx

Virgin glass bottles (avoided)

The avoided production of glass bottles, due to the export of broken glass from the packaging system, has the largest influence on the following environmental impact categories:

- global warming potential, due to avoided CO_2 emissions
- photchemical ozon formation, due to avoided emissions of HC and NMVOC to air
- acidification potential, due to avoided emissions of SO_2, NO_2 and NOx, and
- nutrification potential, due to avoided emissions of NO_2,NOx and NH_3

Waste generation

The slags & ashes are generated by the incineration of glass and tinplate.

Resource demand

Tin resources are used in the production of caps from tinplate.

Sensitivity analyses

Sensitivity analyses were conducted as described in section 2.13. The quantitative results are presented in Table 4.14.

Table 4.14
Results from the quantitative sensitivity analyses made on the packaging system with 33 cl disposable green bottles. Functional unit: packaging and distribution of 1000 litres.

Parameters	Base case [g/1000 l beverage]	50/50 allocation [% of base case]	Bottle weight (+ 20 %) [% of base case]	Electricity, Fragmented markets [% of base case]	Electricity, European base load [% of base case]
CO_2	3,38E+05	101	102	81	83
SO_2	9,45E+02	101	101	76	142
NO_x	1,82E+03	101	103	86	92
VOC, total	9,30E+02	101	101	22	50

Allocation procedure

In the base case the discarded glass from the system replaces 100% virgin glass materials in other systems. The used recycled glass from other systems is in the same manner replaced by virgin materials in these systems. In this sensitivity scenario the discarded glass replaces 50% virgin materials and 50% other recycled glass, and the recycled glass coming into the system is replaced by 50% virgin materials and 50% other recycled glass. The results in Table 4.14 show that the choice of allocation procedure for recycled glass does not influence the results.

Bottle weight

The bottle weight is 145 g in the base case. This could be compared to 160 g in the previous study. In the sensitivity scenario the bottle weight was increased by 20 % (to 174 g). The results for some of the important inventory parameters are shown in Table 4.14. The bottle weight appears to be of no importance, especially since a bottle weight increase of 20 % is excessive.

Electricity production

The electricity data used in the base case represent coal marginal. Two sensitivity analyses were performed for electricity production (long term base load at fragmented markets and European base load average). It is clear from the results (Table 4.14) that the assumption regarding the electricity production is important.
It should be noted that the large decrease in VOC for these scenarios is almost entirely due to the decrease in CH_4 emissions. Discounting the emissions of CH_4 results in only small changes in emissions of VOC.

Distribution of beverage

The bottles are distributed by medium and heavy trucks in the base case. A sensitivity analysis using data for distribution by light trucks showed a small increase in the environmental impacts, but a noticeable increase in effects concerning NO_x emissions.

Data gaps and omissions

The analysis did not include the production of a large number of ancillary materials.

Production of materials for secondary packagings (boxes, trays and wraparounds), transport packaging (pallets and plastic ligature) and cap inserts is included in the LCA, but the actual packaging production - conversion, nailing etc. - is not included. Neither does the analysis include the environmental impacts of the retailer, nor the private transports to and from the retailer. These omissions affect the total energy demand of the system by approximately 0.5 % and 0.2 % respectively.

Uncertainties

The data quality for the virgin glass bottle production (avoided) is assessed to have medium uncertainty, good completeness and fair representativity. The data quality for the bottle production is assessed to have small uncertainty, good completeness and good representativity.

For further details, see Technical report 2.

5 Aluminium cans

5.1 The systems

33 cl can

The process tree of the packaging systems is illustrated in Figure 5.1. The 33 cl aluminium can is produced from 0.25 mm thick aluminium sheets. To distribute 1000 litres of beverage, 3030 aluminium cans (1000/0.33) are produced. The weight of one 33 cl aluminium can is 14.45 grams.

50 cl can

The process tree of the packaging systems is illustrated in Figure 5.2. The 50 cl aluminium can is produced from 0.26 mm thick aluminium sheets. To distribute 1000 litres of beverage, 2000 aluminium cans (1000/0. 5) are produced. The weight of one 50 cl aluminium can is 18.50 grams.

Recycling rates

This study assumes that 90% of the used aluminium cans are collected for recycling (see Table 2.2). The remaining 10% end up in waste incineration where energy is recovered. A significant share of the aluminium cans are recycled into new cans (Nylin, 1997). However, no detailed information about the share of secondary aluminium in the cans were available within this project. This has no effect on the LCA results (see section 2.7.5).

5.2 Inventory analysis

5.2.1 33 cl aluminium can

Input data

The can, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 5.1. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 3. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

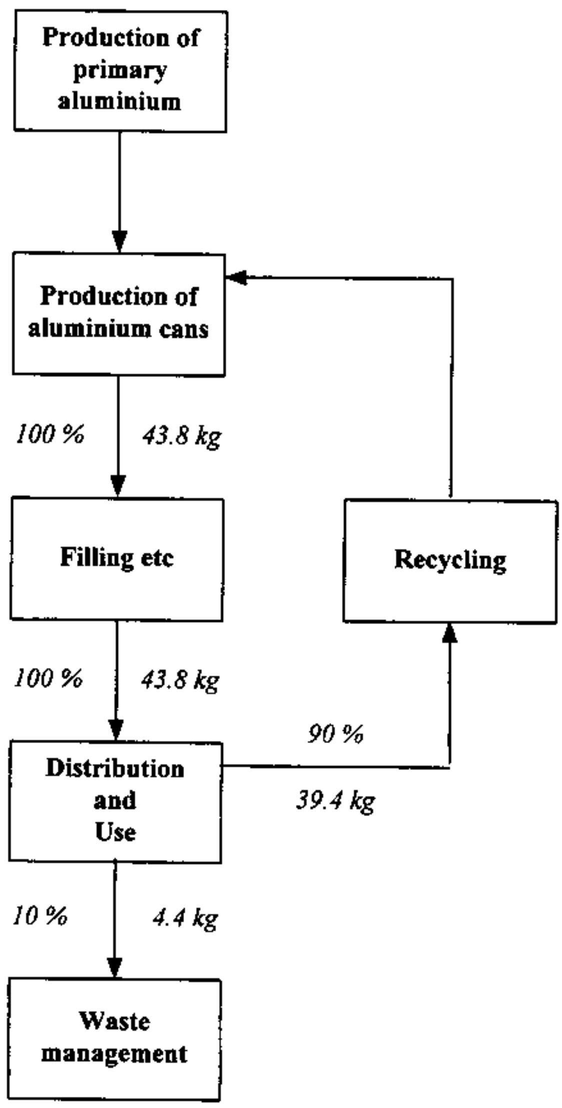

Figure 5.1

Flows of 33 cl aluminium can system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure.

Table 5.1
System parameters for the packaging system with 33 cl aluminium cans. The mass presented refers to the weight of a single item, i.e., one can or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of return	Material to recycling	Material to disposal
Primary packaging	Aluminium can (33 cl)	14.45	100 %	Aluminium	0 %	90 %	10 %
Secondary packaging	Tray (24 cans)	120	50 %	Corrugated board	0 %	20 %	80 %
	Foil for tray (24 cans)	20	33 %	LDPE	0 %	0 %	100 %
	Box (24 cans)	200	17 %	Corrugated board	0 %	20 %	80 %
	Box (6 cans)	50	25 %	Cardboard	0 %	20 %	80 %
	Hi-cone	3.4	25 %	LDPE	0 %	0 %	100 %
Transport packaging	Pallet (2376 cans)	22000	100 %	Wood	95 %	0 %	5 %
	Plastic ligature (2376 cans)	20	75 %	LDPE	0 %	70 %	30 %
	Glue	2	25 %	Casein/urea/H_2O	0 %	0 %	100 %

Energy demand

An explanation of the disaggregation made in Table 5.2 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 5.2
Energy demand at final use for the packaging system with 33 cl aluminium cans. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity. total	*kWh*	3.02E+02	-1.66	3.01E+02
Electricity. coal marginal	*kWh*	*2.99E+02*	*-1.66*	*2.98E+02*
Fossil fuel, total	MJ	1.39E+03	-4.05E+02	9.89E+02
Diesel, heavy & medium truck (highway)	*MJ*	*1.86E+02*	*2.19*	*1.88E+02*
Diesel, heavy & medium truck (rural)	*MJ*	*1.03E+02*	*-6.48E-02*	*1.02E+02*
Diesel, heavy & medium truck (urban)	*MJ*	*7.40E+01*	*7.64*	*8.17E+01*
Diesel, ship (4-stroke)	*MJ*	*1.57E+01*	*1.01E+01*	*2.58E+01*
Fuel oil, ship (2-stroke)	*MJ*	*5.37E+01*	*0*	*5.37E+01*
LPG, thermal	*MJ*	*2.94E+01*	*0*	*2.94E+01*
Natural gas (>100 kW)	*MJ*	*6.44E+02*	*-1.94E+02*	*4.49E+02*
Natural gas	*MJ*	*2.57E+01*	*0*	*2.57E+01*
Natural gas, feedstock	*MJ*	*4.20E+01*	*0*	*4.20E+01*
Oil, feedstock	*MJ*	*5.85E+01*	*0*	*5.85E+01*
Oil, heavy fuel	*MJ*	*1.05E+02*	*9.81*	*1.14E+02*
Oil, heavy, feedstock	*MJ*	*3.50E+01*	*0*	*3.50E+01*
Oil, light fuel	*MJ*	*3.64*	*-2.41E+02*	*-2.37E+02*
Renewable fuel, total	MJ	1.11E+01	3.95	1.50E+01
Bark	*MJ*	*1.11E+01*	*3.95*	*1.50E+01*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 5.3. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 3.

Table 5.3

Selection of inventory results for the packaging system with 33 cl aluminium cans. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Bauxite	g	2.27E+04	0	2.27E+04
Brown coal	g	1.70E+03	-9.29E+01	1.61E+03
Coal	g	3.74E+02	0	3.74E+02
Coal, feedstock	g	5.88E+02	0	5.88E+02
Crude oil	g	2.30E+04	-5.46E+03	1.76E+04
Crude oil, feedstock	g	4.25E+03	-9.80E-05	4.25E+03
Hard coal	g	1.71E+05	-1.05E+03	1.70E+05
Hydro power-water	g	5.36E+09	-2.22E+09	3.14E+09
Land use	m^2*year	2.15E+02	1.83E+02	3.98E+02
Limestone	g	1.11E+03	0	1.11E+03
Mn	g	9.44E+01	-6.83E-06	9.44E+01
NaCl	g	4.94E+01	-2.01E-03	4.94E+01
Natural gas	g	1.55E+04	-4.24E+03	1.13E+04
Natural gas, feedstock	g	7.78E+02	0	7.78E+02
Oil, feedstock	g	3.93E+02	0	3.93E+02
Salt	g	3.43E+02	0	3.43E+02
Softwood	g	4.75E+01	-2.64E-01	4.72E+01
Water	g	3.29E+07	-1.82E+05	3.28E+07
Non-elementary inflows				
Alum	g	3.56E+01	1.78E+01	5.34E+01
Aluminium hydroxide	g	7.36E+01	0	7.36E+01
Argon	g	1.75E+01	0	1.75E+01
Bark	g	6.53E+02	2.32E+02	8.85E+02
$Ca(OH)_2$	g	4.01E+02	0	4.01E+02
$CaCO_3$	g	2.98E+01	1.49E+01	4.47E+01
Calcium fluoride	g	1.60E+02	0	1.60E+02
CaO	g	7.92E+01	3.94E+01	1.19E+02
Carbon	g	1.93E+02	0	1.93E+02
Chlorine	g	1.05E+01	0	1.05E+01
Defoamer	g	1.30E+01	5.29	1.83E+01

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	Unit	Packaging system	Effects on other product systems	Total
Finish	g	9.38E+01	0	9.38E+01
Glue	g	6.31E+01	0	6.31E+01
H_2SO_4	g	1.27E+02	6.35E+01	1.91E+02
Na_2SO_4	g	4.71E+01	2.36E+01	7.07E+01
Na_2CO_3	g	2.07E+01	8.17	2.89E+01
NaOH	g	8.87E+01	3.51E+01	1.24E+02
NH_3	g	1.48E+01	0	1.48E+01
Oil	g	4.43E+02	0	4.43E+02
Packaging	g	1.67E+03	0	1.67E+03
Peat	g	3.16E+02	2.52E+01	3.41E+02
Plastic ligature	g	1.91E+01	0	1.91E+01
Polyester for strips	g	2.03E+02	0	2.03E+02
Printing ink	g	1.12E+02	0	1.12E+02
Refractory materials	g	5.41E+01	0	5.41E+01
Retention agents	g	2.30E+01	8.17	3.12E+01
Sizing agents	g	7.33E+01	1.25E+01	8.58E+01
Starch	g	3.11E+02	-1.19E+02	1.92E+02
Steel	g	3.84E+01	0	3.84E+01
Sulphur	g	1.61E+01	9.64E-01	1.71E+01
Sulphuric acid	g	1.85E+02	0	1.85E+02
Washing chemicals	g	4.39E+02	0	4.39E+02
Emissions to air				
Butanol	g	2.09E+01	0	2.09E+01
CH_4	g	1.36E+03	-1.38E+02	1.23E+03
CO	g	6.57E+02	-1.83	6.55E+02
CO_2	g	3.68E+05	-3.13E+04	3.36E+05
HC	g	4.98E+01	-8.27E-02	4.97E+01
HCl	g	1.97E+01	-1.56E-01	1.96E+01
NMVOC	g	7.90E+01	-4.56E+01	3.34E+01
NMVOC, diesel engines	g	4.75E+01	1.99	4.95E+01
NMVOC, electricity-coal	g	5.00	-2.78E-02	4.97
NMVOC, oil combustion	g	5.15E+01	2.24	5.37E+01
NMVOC, power plants	g	2.42	-1.34E-02	2.40
NO_x	g	1.26E+03	-1.34E+01	1.25E+03
SO_2	g	8.17E+02	-1.91E+01	7.98E+02
VOC, diesel engines	g	3.60	-1.99E-02	3.58
Emissions to water				
BOD	g	2.45E+01	-7.21E-05	2.45E+01
BOD-5	g	6.59E+01	2.82E+01	9.41E+01

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	Unit	Packaging system	Effects on other product systems	Total
COD	g	3.42E+02	7.67E+01	4.18E+02
Waste				
Bulk waste, total	g	1.03E+05	-1.21E+04	9.07E+04
Elementary waste, corrugated board	g	*0*	*-5.86E+02*	*-5.86E+02*
Waste	g	*1.54E+02*	*0*	*1.54E+02*
Waste, bulky	g	*5.44E+04*	*-3.02E+02*	*5.41E+04*
Waste, combustible	g	*6.08E+02*	*0*	*6.08E+02*
Waste, industrial	g	*3.72E+04*	*-1.12E+04*	*2.60E+04*
Waste, inert residues	g	*6.80E+02*	*0*	*6.80E+02*
Waste, inorganic sludges	g	*1.59E+02*	*7.55E+01*	*2.35E+02*
Waste, non hazardous	g	*9.12E+02*	*0*	*9.12E+02*
Waste, other rejects	g	*3.71E+02*	*-8.61E+01*	*2.84E+02*
Waste, red mud	g	*6.58E+03*	*0*	*6.58E+03*
Waste, sludge	g	*7.23E+02*	*-2.42E-10*	*7.23E+02*
Waste, wood	g	*6.42E+02*	*0*	*6.42E+02*
Hazardous waste, total	g	7.06E+03	-1.47E+03	5.59E+03
Waste, hazardous	g	*6.61E+03*	*-1.47E+03*	*5.14E+03*
Waste, oil	g	*3.81E+02*	*0*	*3.81E+02*
Waste, solvent	g	*6.35E+01*	*0*	*6.35E+01*
Slags & ashes, total	g	1.52E+04	1.98E+01	1.52E+04
Waste, ashes	g	*5.09E+03*	*2.79E+01*	*5.12E+03*
Waste, slags & ashes (energy prod,)	g	*1.47E+03*	*-8.14*	*1.46E+03*
Waste, slags & ashes	g	*8.66E+03*	*0*	*8.66E+03*
Nuclear waste, total	g	1.66E+01	1.71E-01	1.68E+01
Waste, highly radioactive	g	*1.63E+01*	*1.72E-01*	*1.65E+01*
Waste, radioactive	g	*3.14E-01*	*-2.24E-04*	*3.14E-01*
Co-products				
Biogas	g	0	-5.51E+01	-5.51E+01
Carbon reused as fuel	g	1.04E+02	0	1.04E+02
Ethylene	g	3.92E+02	0	3.92E+02
Fuel gas	g	4.44E+02	0	4.44E+02
Hydrogen	g	1.06E+02	0	1.06E+02
Layer pads, CB	g	3.03E+02	0	3.03E+02
Plastic ligature	g	1.33E+01	0	1.33E+01
Skimmings and dross for recycling	g	7.55E+01	0	7.55E+01
Steel scrap	g	3.84E+01	0	3.84E+01
Synthetic gas (H_2:CO=2:1)	g	1.86E+03	0	1.86E+03

5.2.2 50 cl aluminium can

Input data

The can, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 5.4. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 3. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

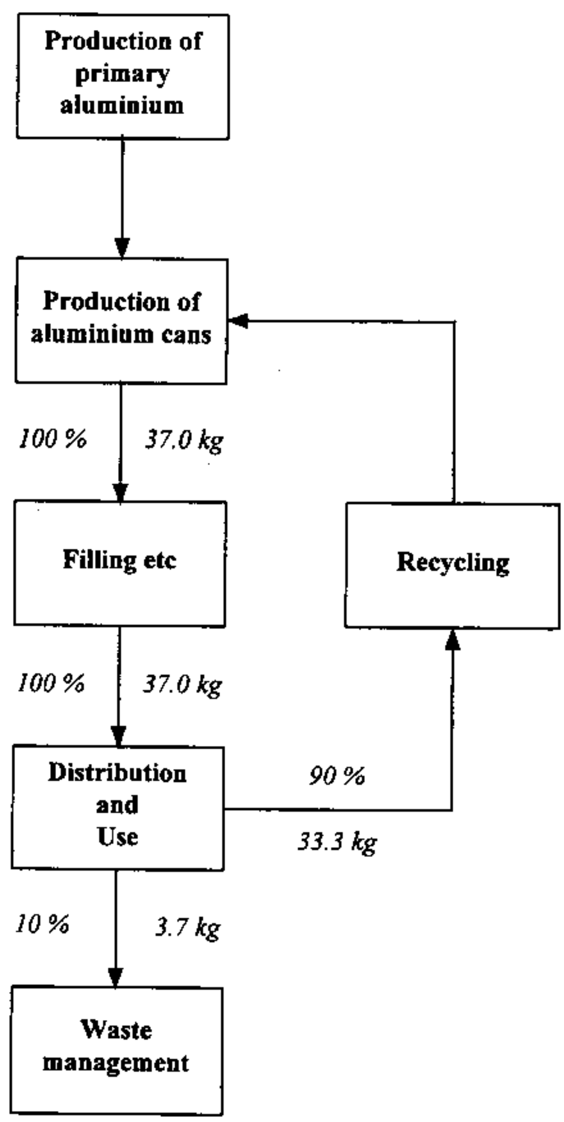

Figure 5.2
Flows of 50 cl aluminium can system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure.

Table 5.4
System parameters for the packaging system with 50 cl aluminium cans. The mass presented refers to the weight of a single item, i.e., one can or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of return	Material to recycling	Material to disposal
Primary packaging	Aluminium can (50 cl)	18.50	100 %	Aluminium	0 %	90 %	10 %
Secondary packaging	Tray (24 cans)	120	50 %	Corrugated board	0 %	20 %	80 %
	Foil for tray (24 cans)	20	33 %	LDPE	0 %	0 %	100 %
	Box (24 cans)	250	17 %	Corrugated board	0 %	20 %	80 %
	Box (6 cans)	60	25 %	Cardboard	0 %	20 %	80 %
	Hi-cone	3.4	25 %	LDPE	0 %	0 %	100 %
Transport packaging	Pallet (1848 cans)	22000	100 %	Wood	95 %	0 %	5 %
	Plastic ligature (1848 cans)	20	75 %	LDPE	0 %	70 %	30 %
	Glue	2	25 %	Casein/urea/H_2O	0 %	0 %	100 %

Energy demand

An explanation of the disaggregation made in Table 5.5 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 5.5
Energy demand at final use for the packaging system with 50 cl aluminium cans. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	2.35E+02	-1.43	2.33E+02
Electricity, coal marginal	*kWh*	*2.32E+02*	*-1.43*	*2.31E+02*
Fossil fuel, total	MJ	1.19E+03	-3.12E+02	8.81E+02
Diesel, heavy & medium truck (highway)	*MJ*	*1.66E+02*	*1.60*	*1.68E+02*
Diesel, heavy & medium truck (rural)	*MJ*	*9.75E+01*	*-4.76E-02*	*9.75E+01*
Diesel, heavy & medium truck (urban)	*MJ*	*7.09E+01*	*5.64*	*7.66E+01*
Diesel, ship (4-stroke)	*MJ*	*1.19E+01*	*7.35*	*1.93E+01*
Fuel oil, ship (2-stroke)	*MJ*	*4.18E+01*	*0*	*4.18E+01*
LPG, thermal	*MJ*	*2.46E+01*	*0*	*2.46E+01*
Natural gas (>100 kW)	*MJ*	*5.34E+02*	*-1.48E+02*	*3.86E+02*
Natural gas	*MJ*	*2.16E+01*	*0*	*2.16E+01*
Natural gas, feedstock	*MJ*	*3.13E+01*	*0*	*3.13E+01*
Oil, feedstock	*MJ*	*4.74E+01*	*0*	*4.74E+01*
Oil, heavy fuel	*MJ*	*9.33E+01*	*7.13*	*1.00E+02*
Oil, heavy, feedstock	*MJ*	*3.35E+01*	*0*	*3.35E+01*
Oil, light fuel	*MJ*	*2.72*	*-1.86E+02*	*-1.83E+02*
Renewable fuel, total	MJ	8.46	2.87	1.13E+01
Bark	*MJ*	*8.46*	*2.87*	*1.13E+01*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 5.6. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 3.

Table 5.6

Inventory results for the packaging system with 50 cl aluminium cans. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Bauxite	g	1.76E+04	0	1.76E+04
Brown coal	g	1.36E+03	-7.29E+01	1.28E+03
Coal	g	3.21E+02	0	3.21E+02
Coal, feedstock	g	4.55E+02	0	4.55E+02
Crude oil	g	1.99E+04	-4.25E+03	1.56E+04
Crude oil, feedstock	g	3.35E+03	-8.34E-05	3.35E+03
Hard coal	g	1.32E+05	-8.96E+02	1.32E+05
Hydro power-water	g	4.00E+09	-1.66E+09	2.34E+09
Land use	m^2•year	1.62E+02	1.35E+02	2.97E+02
Limestone	g	8.67E+02	0	8.67E+02
Mn	g	7.30E+01	-5.85E-06	7.30E+01
NaCl	g	4.65E+01	-1.74E-03	4.65E+01
Natural gas	g	1.29E+04	-3.25E+03	9.63E+03
Natural gas, feedstock	g	5.80E+02	0	5.80E+02
Oil, feedstock	g	3.90E+02	0	3.90E+02
Salt	g	2.66E+02	0	2.66E+02
Softwood	g	3.68E+01	-2.26E-01	3.66E+01
Water	g	2.55E+07	-1.57E+05	2.54E+07
Non-elementary inflows				
Alum	g	2.63E+01	1.29E+01	3.93E+01
Aluminium hydroxide	g	5.70E+01	0	5.70E+01
Argon	g	1.46E+01	0	1.46E+01
Bark	g	4.97E+02	1.68E+02	6.66E+02
$Ca(OH)_2$	g	3.07E+02	0	3.07E+02
$CaCO_3$	g	2.21E+01	1.08E+01	3.29E+01
Calcium fluoride	g	1.24E+02	0	1.24E+02
CaO	g	5.87E+01	2.87E+01	8.73E+01
Carbon	g	1.49E+02	0	1.49E+02
Defoamer	g	9.65	3.84	1.35E+01
Finish	g	7.53E+01	0	7.53E+01

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	Unit	Packaging system	Effects on other product systems	Total
Glue	g	4.18E+01	0	4.18E+01
H_2SO_4	g	9.42E+01	4.61E+01	1.40E+02
Na_2SO_4	g	3.49E+01	1.71E+01	5.20E+01
Na_2CO_3	g	1.53E+01	5.94	2.12E+01
NaOH	g	6.56E+01	2.55E+01	9.11E+01
NH_3	g	1.09E+01	0	1.09E+01
Oil	g	4.25E+02	0	4.25E+02
Packaging	g	1.38E+03	0	1.38E+03
Peat	g	2.32E+02	1.83E+01	2.50E+02
Plastic ligature	g	1.63E+01	0	1.63E+01
Polyester for strips	g	1.35E+02	0	1.35E+02
Printing ink	g	1.27E+02	0	1.27E+02
Refractory materials	g	4.19E+01	0	4.19E+01
Retention agents	g	1.70E+01	5.94	2.30E+01
Sizing agents	g	5.42E+01	9.08	6.33E+01
Starch	g	2.29E+02	-8.63E+01	1.42E+02
Steel	g	2.97E+01	0	2.97E+01
Sulphur	g	1.18E+01	7.01E-01	1.25E+01
Sulphuric acid	g	1.43E+02	0	1.43E+02
Washing chemicals	g	3.82E+02	0	3.82E+02
Emissions to air				
Butanol	g	2.11E+01	0	2.11E+01
CH_4	g	1.07E+03	-1.03E+02	9.64E+02
CO	g	5.17E+02	-1.64	5.16E+02
CO_2	g	2.93E+05	-2.43E+04	2.68E+05
HC	g	3.95E+01	-7.12E-02	3.94E+01
HCl	g	1.53E+01	-1.30E-01	1.52E+01
NMVOC	g	7.22E+01	-3.53E+01	3.69E+01
NMVOC, diesel engines	g	4.24E+01	1.46	4.38E+01
NMVOC, electricity-coal	g	3.88	-2.39E-02	3.86
NMVOC, oil combustion	g	4.47E+01	1.63	4.63E+01
NO_x	g	1.03E+03	-1.16E+01	1.02E+03
SO_2	g	6.45E+02	-1.52E+01	6.30E+02
VOC, diesel engines	g	2.79	-1.71E-02	2.78
Emissions to water				
BOD	g	2.43E+01	-6.12E-05	2.43E+01
BOD-5	g	4.87E+01	2.05E+01	6.92E+01
COD	g	2.89E+02	5.57E+01	3.44E+02

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	Unit	Packaging system	Effects on other product systems	Total
Waste				
Bulk waste, total	g	8.11E+04	-9.26E+03	7.19E+04
Elementary waste, corrugated board	g	*0*	*-4.26E+02*	*-4.26E+02*
Waste	g	*1.03E+02*	*0*	*1.03E+02*
Waste, bulky	g	*4.22E+04*	*-2.60E+02*	*4.19E+04*
Waste, combustible	g	*4.04E+02*	*0*	*4.04E+02*
Waste, industrial	g	*3.10E+04*	*-8.54E+03*	*2.24E+04*
Waste, inert residues	g	*5.26E+02*	*0*	*5.26E+02*
Waste, inorganic sludges	g	*1.18E+02*	*5.49E+01*	*1.73E+02*
Waste, non hazardous	g	*7.65E+02*	*0*	*7.65E+02*
Waste, other rejects	g	*2.73E+02*	*-6.25E+01*	*2.10E+02*
Waste, red mud	g	*5.09E+03*	*0*	*5.09E+03*
Waste, sludge	g	*4.80E+02*	*-2.08E-10*	*4.80E+02*
Waste, wood	g	*4.26E+02*	*0*	*4.26E+02*
Hazardous waste, total	g	5.73E+03	-1.13E+03	4.61E+03
Waste, hazardous	g	*5.40E+03*	*-1.13E+03*	*4.27E+03*
Waste, oil	g	*2.89E+02*	*0*	*2.89E+02*
Slags & ashes, total	g	1.27E+04	1.33E+01	1.27E+04
Waste, ashes	g	*4.27E+03*	*2.03E+01*	*4.29E+03*
Waste, slags & ashes (energy prod.)	g	*1.14E+03*	*-7.00*	*1.13E+03*
Waste, slags & ashes	g	*7.31E+03*	*0*	*7.31E+03*
Nuclear waste, total	g	1.49E+01	1.24E-01	1.50E+01
Waste, highly radioactive	g	*1.46E+01*	*1.25E-01*	*1.47E+01*
Waste, radioactive	g	*2.46E-01*	*-3.70E-04*	*2.46E-01*
Co-products				
Biogas	g	0	-4.00E+01	-4.00E+01
Carbon reused as fuel	g	8.08E+01	0	8.08E+01
Ethylene	g	3.90E+02	0	3.90E+02
Fuel gas	g	4.41E+02	0	4.41E+02
Hydrogen	g	1.05E+02	0	1.05E+02
Layer pads, CB	g	2.01E+02	0	2.01E+02
Plastic ligature	g	1.15E+01	0	1.15E+01
Skimmings and dross for recycling	g	5.84E+01	0	5.84E+01
Steel scrap	g	2.97E+01	0	2.97E+01
Synthetic gas (H_2:CO=2:1)	g	1.85E+03	0	1.85E+03

5.3 Impact assessment

This section presents results from the impact assessment of packaging systems with aluminium cans. The most important characterisation calculations and results are presented in Tables 5.7 and 5.8. For a full presentation of the classification and characterisation, we refer to Technical report 3.

Normalisation results are presented in Tables 5.9 and 5.10. Weighting results are presented in Tables 5.11 and 5.12.

Table 5.7

Classification and characterisation of the packaging system with 33 cl aluminium cans. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NOx	1.35 E-03	1.71	-1.81E-02	1.69
Total		**1.72**	**-2.52E-02**	**1.70**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
Butanol	4.00E-04	8.36E-03	0	8.36E-03
CH4	7.00E-06	9.55E-03	-9.68E-04	8.58E-03
CO	3.00E-05	1.97E-02	-5.49E-05	1.96E-02
HC	6.00E-04	2.99E-02	-4.96E-05	2.98E-02
NMVOC	4.00E-04	3.16E-02	-1.82E-02	1.33E-02
NMVOC, diesel engines	6.00E-04	2.85E-02	1.19E-03	2.97E-02
NMVOC, electricity-coal	8.00E-04	4.00E-03	-2.23E-05	3.98E-03
NMVOC, oil combustion	3.00E-04	1.54E-02	6.71E-04	1.61E-02
NMVOC, power plants	5.00E-04	1.21E-03	-6.71E-06	1.20E-03
VOC, diesel engines	6.00E-04	2.16E-03	-1.19E-05	2.15E-03
Total		**1.52E-01**	**-1.78E-02**	**1.34E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	1.73E-02	-1.38E-04	1.72E-02
NO_x	7.00E-04	8.85E-01	-9.41E-03	8.75E-01
SO_2	1.00E-03	8.17E-01	-1.91E-02	7.98E-01
Total		**1.73**	**-2.77E-02**	**1.71**

Global warming potential (GWP) [kg CO_2-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH4	2.50E-02	3.41E+01	-3.46	3.06E+01
CO	2.00E-03	1.31	-3.66E-03	1.31
CO2	1.00E-03	3.68E+02	-3.13E+01	3.36E+02
Total		**4.04E+02**	**-3.48E+01**	**3.70E+02**

Table 5.8

Classification and characterisation of the packaging system with 50 cl aluminium cans. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NOx	1.35 E-03	1.39	-1.56E-02	1.37
Total		**1.40**	**-2.10E-02**	**1.38**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
Butanol	4.00E-04	8.44E-03	0	8.44E-03
CH4	7.00E-06	7.46E-03	-7.18E-04	6.74E-03
CO	3.00E-05	1.55E-02	-4.93E-05	1.55E-02
HC	6.00E-04	2.37E-02	-4.27E-05	2.36E-02
NMVOC	4.00E-04	2.89E-02	-1.41E-02	1.48E-02
NMVOC, diesel engines	6.00E-04	2.54E-02	8.74E-04	2.63E-02
NMVOC, electricity-coal	8.00E-04	3.10E-03	-1.92E-05	3.08E-03
NMVOC, oil combustion	3.00E-04	1.34E-02	4.88E-04	1.39E-02
VOC, diesel engines	6.00E-04	1.68E-03	-1.03E-05	1.67E-03
Total		**1.30E-01**	**-1.39E-02**	**1.16E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	1.35E-02	-1.15E-04	1.34E-02
NOx	7.00E-04	7.21E-01	-8.11E-03	7.13E-01
SO2	1.00E-03	6.45E-01	-1.52E-02	6.30E-01
Total		**1.39**	**-2.27E-02**	**1.37**

Global warming potential (GWP) [kg CO_2-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH4	2.50E-02	2.67E+01	-2.56	2.41E+01
CO	2.00E-03	1.03	-3.29E-03	1.03
CO2	1.00E-03	2.93E+02	-2.43E+01	2.68E+02
Total		**3.21E+02**	**-2.68E+01**	**2.94E+02**

Table 5.9
Normalisation results for the packaging system with 33 cl aluminium cans. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Environmental impact categories	Normalisation reference (1)	Packaging system [PEWDK90] (2)	Effects on other product systems [PEWDK90] (2)	Total [PEWDK90] (2)
Environmental impacts				
Global warming (GWP)	8700	4.65E-02	-4.00E-03	4.25E-02
Photochemical ozone formation (POCP)	20	7.58E-03	-8.92E-04	6.69E-03
Acidification (AP)	124	1.40E-02	-2.23E-04	1.38E-02
Nutrient enrichment (NP)	298	5.78E-03	-8.45E-05	5.70E-03
Waste				
Bulk waste (non-hazardous)	1350	7.61E-02	-8.97E-03	6.71E-02
Hazardous waste	20.7	3.41E-01	-7.12E-02	2.70E-01
Slag and ashes	320	4.35E-02	5.64E-05	4.35E-02
Nuclear waste	0.159	1.05E-01	1.08E-03	1.06E-01
Resources				
Oil	590	4.69E-02	-9.26E-03	3.77E-02
Coal	570	1.84E-01	-1.12E-03	1.83E-01
Brown coal	250	6.81E-03	-3.72E-04	6.44E-03
Natural gas	310	5.27E-02	-1.37E-02	3.90E-02
Aluminium	3.1	1.84	-3.40E-07	1.84
Manganese	1.8	5.24E-02	-3.80E-09	5.24E-02

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 5.10
Normalisation results for the packaging system with 50 cl aluminium cans. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	3.69E-02	-3.09E-03	3.38E-02
Photochemical ozone formation (POCP)	20	6.48E-03	-6.94E-04	5.79E-03
Acidification (AP)	124	1.12E-02	-1.83E-04	1.10E-02
Nutrient enrichment (NP)	298	4.71E-03	-7.06E-05	4.64E-03
Waste				
Bulk waste (non-hazardous)	1350	6.04E-02	-6.86E-03	5.36E-02
Hazardous waste	20.7	2.77E-01	-5.45E-02	2.22E-01
Slag and ashes	320	3.64E-02	3.79E-05	3.64E-02
Nuclear waste	0.159	9.34E-02	7.82E-04	9.42E-02
Resources				
Oil	590	4.00E-02	-7.20E-03	3.28E-02
Coal	570	1.43E-01	-9.62E-04	1.42E-01
Brown coal	250	5.42E-03	-2.92E-04	5.13E-03
Natural gas	310	4.34E-02	-1.05E-02	3.29E-02
Aluminium	3.1	1.43	-2.93E-07	1.43
Manganese	1.8	4.06E-02	-3.25E-09	4.06E-02

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 5.11

Weighting results for the packaging system with 33 cl aluminium cans. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	6.04E-02	-5.20E-03	5.52E-02
Photochemical ozone formation (POCP)	1.2	9.09E-03	-1.07E-03	8.02E-03
Acidification (AP)	1.3	1.82E-02	-2.90E-04	1.79E-02
Nutrient enrichment (NP)	1.2	6.94E-03	-1.01E-04	6.84E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	8.37E-02	-9.86E-03	7.38E-02
Hazardous waste	1.1	3.75E-01	-7.83E-02	2.97E-01
Slag and ashes	1.1	4.78E-02	6.21E-05	4.79E-02
Nuclear waste	1.1	1.15E-01	1.19E-03	1.16E-01
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	1.08E-03	-2.13E-04	8.66E-04
Coal	5.80E-03	1.07E-03	-6.51E-06	1.06E-03
Brown coal	2.60E-03	1.77E-05	-9.66E-07	1.67E-05
Natural gas	1.60E-02	8.43E-04	-2.19E-04	6.24E-04
Aluminium	5.10E-03	9.39E-03	-1.73E-09	9.39E-03
Manganese	1.20E-02	6.29E-04	-4.55E-11	6.29E-04

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

Table 5.12

Weighting results for the packaging system with 50 cl aluminium cans. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	4,80E-02	-4,01E-03	4,40E-02
Photochemical ozone formation (POCP)	1.2	7,78E-03	-8,33E-04	6,94E-03
Acidification (AP)	1.3	1,46E-02	-2,38E-04	1,43E-02
Nutrient enrichment (NP)	1.2	5,66E-03	-8,47E-05	5,57E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	6,65E-02	-7,55E-03	5,89E-02
Hazardous waste	1.1	3,05E-01	-5,99E-02	2,45E-01
Slag and ashes	1.1	4,00E-02	4,17E-05	4,00E-02
Nuclear waste	1.1	1,03E-01	8,60E-04	1,04E-01
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	9,21E-04	-1,65E-04	7,55E-04
Coal	5.80E-03	8,30E-04	-5,58E-06	8,24E-04
Brown coal	2.60E-03	1,41E-05	-7,59E-07	1,33E-05
Natural gas	1.60E-02	6,95E-04	-1,68E-04	5,27E-04
Aluminium	5.10E-03	7,28E-03	-1,49E-09	7,28E-03
Manganese	1.20E-02	4,87E-04	-3,90E-11	4,87E-04

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

5.4 Interpretation

Important impacts

The packaging systems with aluminium cans contribute most to the following non-toxicological environmental impacts (see Tables 5.9-5.12):

- global warming (GWP), and
- acidification (AP)

Waste and resources

The aluminium can systems contribute a relatively large share (>100 mPET) of the target levels for generation of hazardous waste and nuclear waste. They also contribute significantly (more than approximately 1 mPR) to the depletion of aluminium resources.

Important processes

The most important processes for the environmental impacts of the 33 cl aluminium can system are presented in table 5.13

Table 5.13
The most important processes of the 33 cl aluminium can system. The figures are given in % of the net total potential environmental impact.

	GWP	POCP	AP	NP
5. Electrolysis etc.	27	15	22	16
8. Strip rolling	13			
11. Can production	23	14	14	15
30. LDPE production		12		
44. Remelting	14		10	10
46. Distribution of beverage		25		14
67. Alternative energy production		-14		

Electrolysis etc.

The largest contributions to GWP, AP and NP are caused by the processes included in electrolysis etc., *i.e.* electrolysis, casting, anode production, petroleum coke production, pitch production, cathode production and AlF_3 production. The main contributing parameters are CO_2 (GWP), SO_2 (AP), and NO_x (AP and NP).

Can production

The production of aluminium cans mainly contributes to global warming (GWP) due to emissions of carbon dioxide.

Distribution of beverage

The largest contributions to photochemical oxidant creation (POCP) are caused by emissions of NMVOC and NMVOC from diesel engines, arising from the distribution of beverage.

Waste generation

The hazardous waste consists mainly of oil and unspecified hazardous waste. The oil is generated at strip rolling and at can production. The unspecified hazardous waste is generated at production of epoxy resins (used as inside coatings), at strip rolling and at can production.

Resource demand

The depletion of aluminium (*i.e.* the resource bauxite) arises from the bauxite mining.

Electricity production

The electricity production is important for the results of this LCA. In the base-case scenario, electricity production is responsible for more than half of the net CO_2 emissions and approximately half of the SO_2 and NO_X emissions.

Sensitivity analyses

Sensitivity analyses were carried through as described in section 2.13. The quantitative results are presented in Table 5.14.

Table 5.14

Results from the quantitative sensitivity analyses made of the packaging system with the 33 cl aluminium can. Functional unit: packaging and distribution of 1000 litres.

	Base case [g/1000 l beverage]	Can weight (+ 20 %) [% of base case]	Distribution (light truck) [% of base case]	Electricity, Natural gas marginal [% of base case]	Electricity, fragmented markets [% of base case]	Electricity, European base load [% of base case]	98.5% collection rate [% of base case]
CO_2	3,36E+05	120	104	72	87	68	87
SO_2	7,98E+02	123	102	48	76	189	74
NO_x	1,25E+03	118	110	68	86	79	86
VOC, total	2,77E+02	113	113	89	95	115	100

Can weight

The can weight is 14.45 grams in the base case. This could be compared to 15.00 grams in the previous study. A sensitivity scenario corresponding to an increase of the can weight by 20 % (17.34 g) was performed. The results for some important inventory parameters are shown in table 5.14. The results are increased between 13 and 23%.

Distribution of beverage

The transport data used in the distribution of beverage represent a mix of different modes of conveyance. A sensitivity analysis regarding the distribution of beverage was performed using data for distribution by light trucks. The mode of conveyance appeared to be of minor importance, especially for CO_2 and SO_2 (table 5.14).

Allocation methods

The allocation method can be of great importance since the difference between the amounts of virgin aluminium and recycled aluminium is large in the assessment. The actual significance is difficult to quantify since no data has been available about the true amount of recycled aluminium in the aluminium cans.

Use of recycled aluminium

Since we use a closed-loop approach for aluminium cans, the inflow of secondary material in our calculations depends on the recycling rate of used aluminium cans. The alternative fate of the secondary aluminium is to be recycled into another aluminium product (see Main report, section 2.7.5). Hence, the share of recycled aluminium in the packaging systems has no effect on the LCA results.

Amount of inside coatings

The amount of inside coatings differs between the cans that are used for beer and for those that are used for soft drinks (the amount is larger in the soft-drink cans). A sensitivity analysis regarding this amount was performed for the steel can, where the amount of inside coatings was increased to the amount used for soft-drink cans. The amount of inside coatings appeared to be of minor importance (see Technical report 4, table 5.3).

Electricity production

The electricity data used in the base case is coal marginal. Three sensitivity analyses were performed for electricity production (natural gas marginal, long term base load at fragmented markets and European base load average). It is clear from the results (table 5.14) that the assumption regarding the electricity production is important.

Collection rate

The collection rate is 90 % in the base case. A sensitivity analysis regarding the collection rate was performed. The collection rate was increased from 90% (as in the base case) to 98.5 %. The results for some of the important inventory parameters are shown in table 5.14.

Data gaps and omissions

There are no known significant data gaps in the inventory analysis of this study. The analysis did not include the production of a large number of ancillary materials. The most important non-elementary inflows are packaging material used at the strip rolling plant and washing chemicals used at the can production. The effect of the cut-off of packaging materials is estimated not to be significant. The effect of the cut-off of washing chemicals can however be of some significance (see Technical report 3).

Production of materials for secondary packagings (trays, boxes etc.) and pallets is included in the LCA, but the actual packaging production - conversion, nailing etc. - is not included.

The environmental impacts of the retailer and the private transport home from the retailer were not included in this study. For aluminium cans, these impacts are insignificant (see Technical report 3).

Uncertainties

The data used for electrolysis are collected from the European Aluminium Association (EAA), with fair representativity, good completeness and medium uncertainty. For can production plant specific data were used. They are estimated to be fairly representative and complete. The uncertainty of these data is estimated to be medium. The data used for distribution of the beverage are assessed to have medium uncertainty and good completeness and representativity.

For further details, se Technical report 3.

6 Steel cans

6.1 The systems

33 cl can

The process tree of the packaging systems is illustrated in Figure 6.1. The 33 cl steel can is produced from tinplate sheets. The sheets are rolled from ingots, produced from 82% primary tin-steel and 18% secondary steel. To distribute 1000 litres of beverage, 3030 steel cans (1000/0.33) are produced. The weight of one 33 cl steel can is 28.2 grams.

50 cl can

The process tree of the packaging systems is illustrated in Figure 6.2. The 50 cl steel can is produced from tinplate sheets. The sheets are rolled from ingots, out of which 82% are made of primary tinsteel and 18% of secondary steel. To distribute 1000 litres of beverage, 2000 steel cans (1000/0. 5) are produced. The weight of one 50 cl steel can is 40.2 grams.

Recycling rates

This study assumes that 90% of the used steel cans are collected for recycling (see Table 2.2). The remaining 10% end up in waste incineration where energy is recovered.

6.2 Inventory analysis

6.2.1 33 cl steel can

Input data

The can, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 6.1. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 4. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

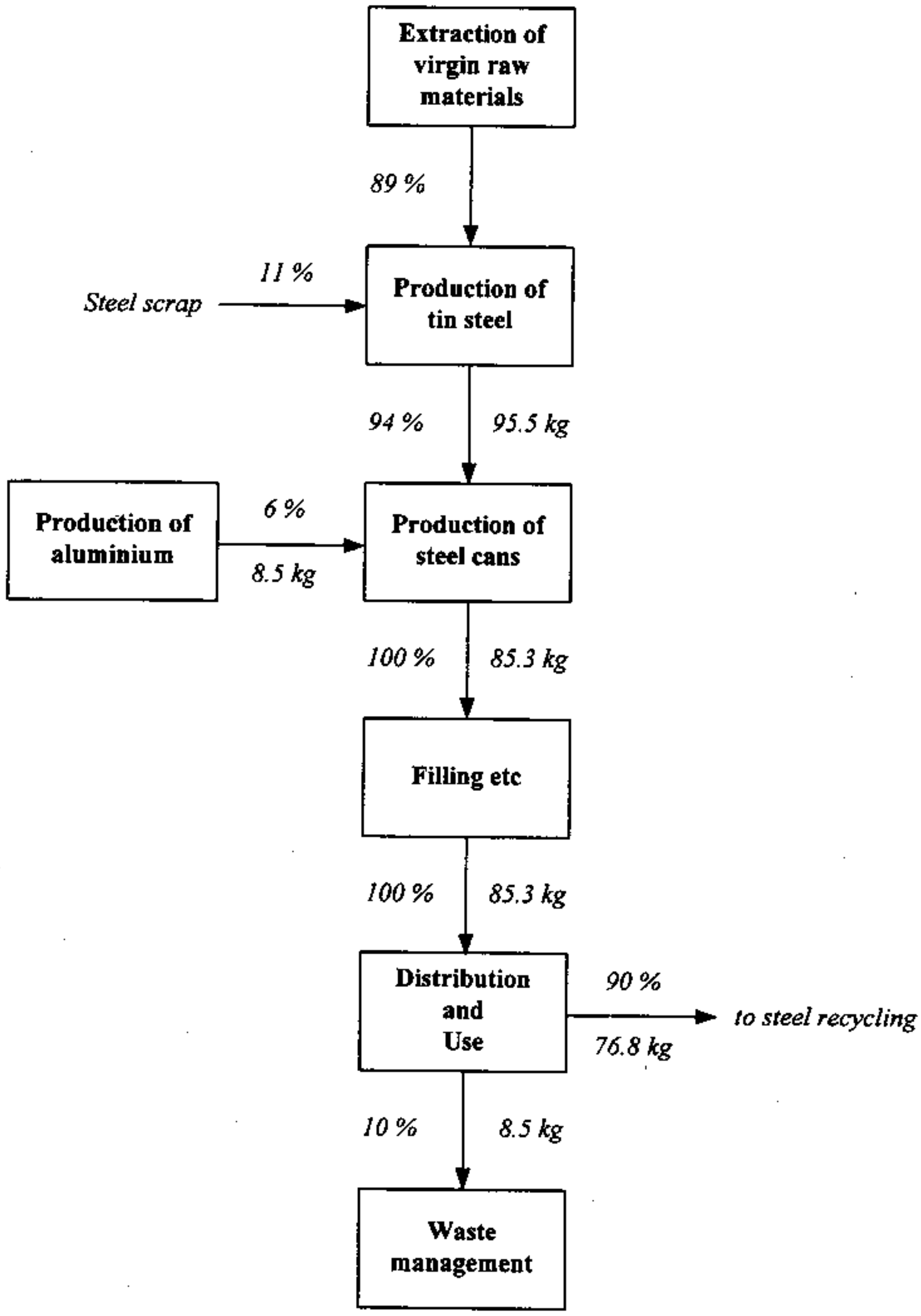

Figure 6.1
Flows of 33 cl steel can system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure. The mass balances do not add up due to material losses etc. that are not presented in the figure.

Table 6.1
System parameters for the packaging system with 33 cl steel cans. The mass presented refers to the weight of a single item, i.e., one can or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of return	Material to recycling	Material to disposal
Primary packaging	Steel can (33 cl)	28.16	100 %	Steel/Al	0 %	90 %	10 %
Secondary packaging	Tray (24 cans)	120	50 %	Corrugated board	0 %	20 %	80 %
	Foil for tray (24 cans)	20	33 %	LDPE	0 %	0 %	100 %
	Box (24 cans)	200	17 %	Corrugated board	0 %	20 %	80 %
	Box (6 cans)	50	25 %	Cardboard	0 %	20 %	80 %
	Hi-cone	3.4	25 %	LDPE	0 %	0 %	100 %
Transport packaging	Pallet (2376 cans)	22000	100 %	Wood	95 %	0 %	5 %
	Plastic ligature (2376 cans)	20	75 %	LDPE	0 %	70 %	30 %
	Glue	2	25 %	Casein/urea/H_2O	0 %	0 %	100 %

Energy demand

An explanation of the disaggregation made in Table 6.2 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 6.2

Energy demand at final use for the packaging system with 33 cl steel cans. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	3.44E+02	-3.91E+01	3.05E+02
Electricity, coal marginal	*kWh*	*3.43E+02*	*-3.91E+01*	*3.04E+02*
Fossil fuel, total	MJ	3.88E+03	-2.16E+03	1.72E+03
Coal, feedstock	*MJ*	*3.31E-02*	*-1.65E+03*	*-1.65E+03*
Diesel, heavy & medium truck (highway)	*MJ*	*1.81E+02*	*2.83E+01*	*2.09E+02*
Diesel, heavy & medium truck (rural)	*MJ*	*8.63E+01*	*0*	*8.63E+01*
Diesel, heavy & medium truck (urban)	*MJ*	*8.67E+01*	*-2.97*	*8.37E+01*
Diesel, ship (4-stroke)	*MJ*	*2.74E+01*	*-3.66*	*2.38E+01*
Fuel oil, ship (2-stroke)	*MJ*	*1.71E+02*	*-9.41E+01*	*7.71E+01*
Hard coal, feedstock	*MJ*	*1.80E+03*	*-2.81E+01*	*1.77E+03*
Natural gas (<100 kW)	*MJ*	*0*	*1.78E+01*	*1.78E+01*
Natural gas (>100 kW)	*MJ*	*9.54E+02*	*-1.10E+02*	*8.44E+02*
Natural gas	*MJ*	*3.77E+01*	*0*	*3.77E+01*
Natural gas, feedstock	*MJ*	*1.08E+02*	*0*	*1.08E+02*
Oil	*MJ*	*1.57E+01*	*0*	*1.57E+01*
Oil, feedstock	*MJ*	*1.11E+02*	*0*	*1.11E+02*
Oil, heavy fuel	*MJ*	*1.13E+02*	*-3.03E+01*	*8.28E+01*
Oil, heavy, feedstock	*MJ*	*9.06E+01*	*-4.76E+01*	*4.30E+01*
Oil, light fuel	*MJ*	*3.46E+01*	*-1.93E+02*	*-1.59E+02*
Renewable fuel, total	MJ	1.67E+01	-2.18	1.45E+01
Bark	*MJ*	*1.67E+01*	*-2.18*	*1.45E+01*
Heat etc., total	MJ	-6.07	1.30E+02	1.24E+02
BF-gas	*MJ*	*0*	*4.91E+01*	*4.91E+01*
Coke oven gas	*MJ*	*0*	*8.02E+01*	*8.02E+01*
Total energy		**5.13E+03**	**-2.18E+03**	**2.95E+03**

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 6.3. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 4.

Table 6.3

Selection of inventory results for the packaging system with 33 cl steel cans. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Bauxite	g	3.87E+04	-6.76E+03	3.19E+04
Brown coal	g	2.99E+03	-4.06E+02	2.58E+03
Coal	g	3.04E+02	-1.79E+01	2.86E+02
Coal, feedstock	g	9.89E+02	-1.72E+02	8.17E+02
Crude oil	g	3.30E+04	-1.09E+04	2.21E+04
Crude oil, feedstock	g	7.54E+03	-8.34E+02	6.70E+03
Hard coal	g	3.02E+05	-2.71E+04	2.75E+05
Hydro power-water	g	3.97E+10	-8.20E+09	3.15E+10
Iron ore, 10% Fe	g	8.25E+05	-7.71E+05	5.44E+04
Land use	m^2*year	3.39E+02	4.81E+01	3.87E+02
Limestone	g	2.84E+04	-2.49E+04	3.52E+03
NaCl	g	2.73E+01	-5.67E-02	2.72E+01
Natural gas	g	2.33E+04	-2.60E+03	2.07E+04
Natural gas, feedstock	g	2.26E+03	0	2.26E+03
Salt	g	5.72E+02	-9.96E+01	4.73E+02
Softwood	g	8.74E+01	-7.64	7.98E+01
Tin	g	2.00E+02	0	2.00E+02
Water	g	6.17E+07	-5.29E+06	5.64E+07
Non-elementary inflows				
Alloys	g	4.76E+02	1.49E+01	4.91E+02
Alum	g	6.11E+01	-9.84	5.12E+01
Aluminium hydroxide	g	1.24E+02	-2.16E+01	1.02E+02
Bark	g	9.82E+02	-1.28E+02	8.53E+02
BF-additives	g	3.05E+03	-2.85E+03	2.03E+02
Bottom coat	g	5.26E+01	0	5.26E+01
$Ca(OH)_2$	g	4.64E+02	0	4.64E+02
$CaCO_3$	g	5.12E+01	-8.25	4.29E+01
Calcium fluoride	g	2.69E+02	-4.69E+01	2.22E+02
CaO	g	8.04E+02	-6.46E+02	1.58E+02
Carbon	g	3.25E+02	-5.67E+01	2.68E+02

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	Unit	Packaging system	Effects on other product systems	Total
Coke	g	6.76E+02	-6.32E+02	4.43E+01
Cupper-lubricant	g	1.11E+01	0	1.11E+01
Defoamer	g	2.05E+01	-2.93	1.76E+01
Glue	g	6.28E+01	0	6.28E+01
H_2SO_4	g	2.18E+02	-3.51E+01	1.83E+02
Mobility enhance	g	6.36E+01	0	6.36E+01
Na_2SO_4	g	8.09E+01	-1.30E+01	6.79E+01
Na_2CO_3	g	3.22E+01	-4.52	2.77E+01
NaOH	g	2.62E+02	-1.94E+01	2.43E+02
NH_3	g	1.40E+01	0	1.40E+01
Oil	g	3.17E+02	0	3.17E+02
Oxygen	m^3	0	-3.14E+02	-3.14E+02
Packaging	g	3.50E+02	0	3.50E+02
Paper	g	1.97E+02	0	1.97E+02
Peat	g	3.37E+02	-1.39E+01	3.24E+02
Plastic ligature	g	1.91E+01	0	1.91E+01
Polyester for strips	g	2.49E+01	0	2.49E+01
Printing ink	g	1.05E+02	0	1.05E+02
Refractory materials	g	9.10E+01	-1.59E+01	7.51E+01
Retention agents	g	3.45E+01	-4.52	2.99E+01
Rubber for tightening	g	2.19E+02	0	2.19E+02
Sizing agents	g	8.97E+01	-6.91	8.28E+01
Starch	g	1.20E+02	6.57E+01	1.86E+02
Steel	g	6.45E+01	-1.13E+01	5.33E+01
Sulphur	g	3.84E+02	-5.32E-01	3.83E+02
Sulphuric acid	g	3.11E+02	-5.43E+01	2.57E+02
Wim-lubricant	g	8.30E+01	0	8.30E+01
Wood for pallets and frames	g	1.52E+02	0	1.52E+02
Emissions to air				
CH_4	g	2.33E+03	-1.87E+02	2.14E+03
CO	g	2.41E+03	-1.52E+03	8.87E+02
CO_2	g	6.26E+05	-2.28E+05	3.99E+05
HC	g	8.08E+01	-2.36	7.84E+01
HCl	g	2.77E+01	-6.77	2.09E+01
N_2O	g	3.93	-7.84E-01	3.15
NMVOC	g	9.74E+01	-3.54E+01	6.20E+01
NMVOC, diesel engines	g	6.07E+01	-5.10	5.56E+01
NMVOC, electricity-coal	g	5.73	-6.53E-01	5.07
NMVOC, oil combustion	g	8.66E+01	-3.95E+01	4.72E+01
NMVOC, power plants	g	4.44	-3.89E-01	4.05

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	Unit	Packaging system	Effects on other product systems	Total
NO_x	g	1.92E+03	-4.19E+02	1.50E+03
SO_2	g	1.48E+03	-4.36E+02	1.05E+03
VOC, diesel engines	g	6.32	-5.66E-01	5.75
Emissions to water				
BOD	g	1.66E+01	-2.01E-03	1.66E+01
BOD-5	g	1.06E+02	-1.56E+01	9.02E+01
COD	g	3.61E+02	-4.36E+01	3.17E+02
Tot-P	g	1.43	0	1.43
Waste				
Bulk waste, total	g	2.49E+05	-9.66E+04	1.52E+05
Elementary waste, corrugated board	g	*-8.62E+02*	*3.24E+02*	*-5.38E+02*
Waste	g	*8.32E+04*	*-7.76E+04*	*5.63E+03*
Waste, bulky	g	*9.75E+04*	*-9.55E+03*	*8.79E+04*
Waste, combustible	g	*1.96E+02*	*0*	*1.96E+02*
Waste, industrial	g	*5.50E+04*	*-8.04E+03*	*4.70E+04*
Waste, inert residues	g	*1.15E+03*	*-2.01E+02*	*9.49E+02*
Waste, inorganic sludges	g	*2.67E+02*	*-4.18E+01*	*2.25E+02*
Waste, other rejects	g	*2.28E+02*	*4.76E+01*	*2.75E+02*
Waste, red mud	g	*1.12E+04*	*-1.96E+03*	*9.24E+03*
Waste, sludge	g	*3.87E+01*	*4.14E+02*	*4.53E+02*
Waste, wood	g	*7.11E+02*	*0*	*7.11E+02*
Hazardous waste, total	g	1.06E+04	-9.61E+02	9.66E+03
Waste, emulsions	g	*2.47E+02*	*0*	*2.47E+02*
Waste, hazardous	g	*1.02E+04*	*-9.61E+02*	*9.24E+03*
Waste, oil	g	*4.54E+01*	*-2.66E-01*	*4.52E+01*
Waste, solvent	g	*1.19E+02*	*0*	*1.19E+02*
Slags & ashes, total	g	7.33E+03	2.77E+02	7.61E+03
Waste, ashes (Fe_3O_4)	g	*2.12E+03*	*0*	*2.12E+03*
Waste, ashes	g	*1.39E+02*	*1.91E+02*	*3.30E+02*
Waste, slags & ashes (energy prod.)	g	*1.86E+03*	*-2.00E+02*	*1.66E+03*
Waste, slags & ashes	g	*1.98E+03*	*-1.14E+03*	*8.34E+02*
Waste, slags	g	*1.23E+03*	*1.43E+03*	*2.66E+03*
Nuclear waste, total	g	1.65E+01	2.39	1.89E+01
Waste, highly radioactive	g	*1.59E+01*	*2.46*	*1.84E+01*
Waste, radioactive	g	*5.74E-01*	*-6.94E-02*	*5.04E-01*

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	Unit	Packaging system	Effects on other product systems	Total
Co-products				
Benzene	g	3.33E+02	-3.14E+02	1.89E+01
Biogas	g	-8.10E+01	3.05E+01	-5.05E+01
Carbon reused as fuel	g	1.76E+02	-3.06E+01	1.45E+02
Corrugated board (from layer pads)	g	1.64E+02	0	1.64E+02
Dust	g	5.72E+03	6.28E+01	5.78E+03
Iron(II)sulphate	g	1.56E+03	0	1.56E+03
Iron oxide	g	1.52E+02	0	1.52E+02
Mill scale	g	0	2.48E+02	2.48E+02
Oil	g	4.76E+01	0	4.76E+01
Plastic ligature	g	1.33E+01	0	1.33E+01
Refractories	g	0	-4.71E+02	-4.71E+02
Skimmings and dross for recycling	g	1.27E+02	-2.22E+01	1.05E+02
Slag	g	3.40E+04	-1.83E+04	1.57E+04
Steel scrap	g	6.45E+01	-1.13E+01	5.33E+01
Tar	g	1.02E+03	-9.81E+02	3.86E+01
Tin hydroxide sludge	g	3.80E+01	0	3.80E+01

6.2.2 50 cl steel can

Input data

The can, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 6.4. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 4. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

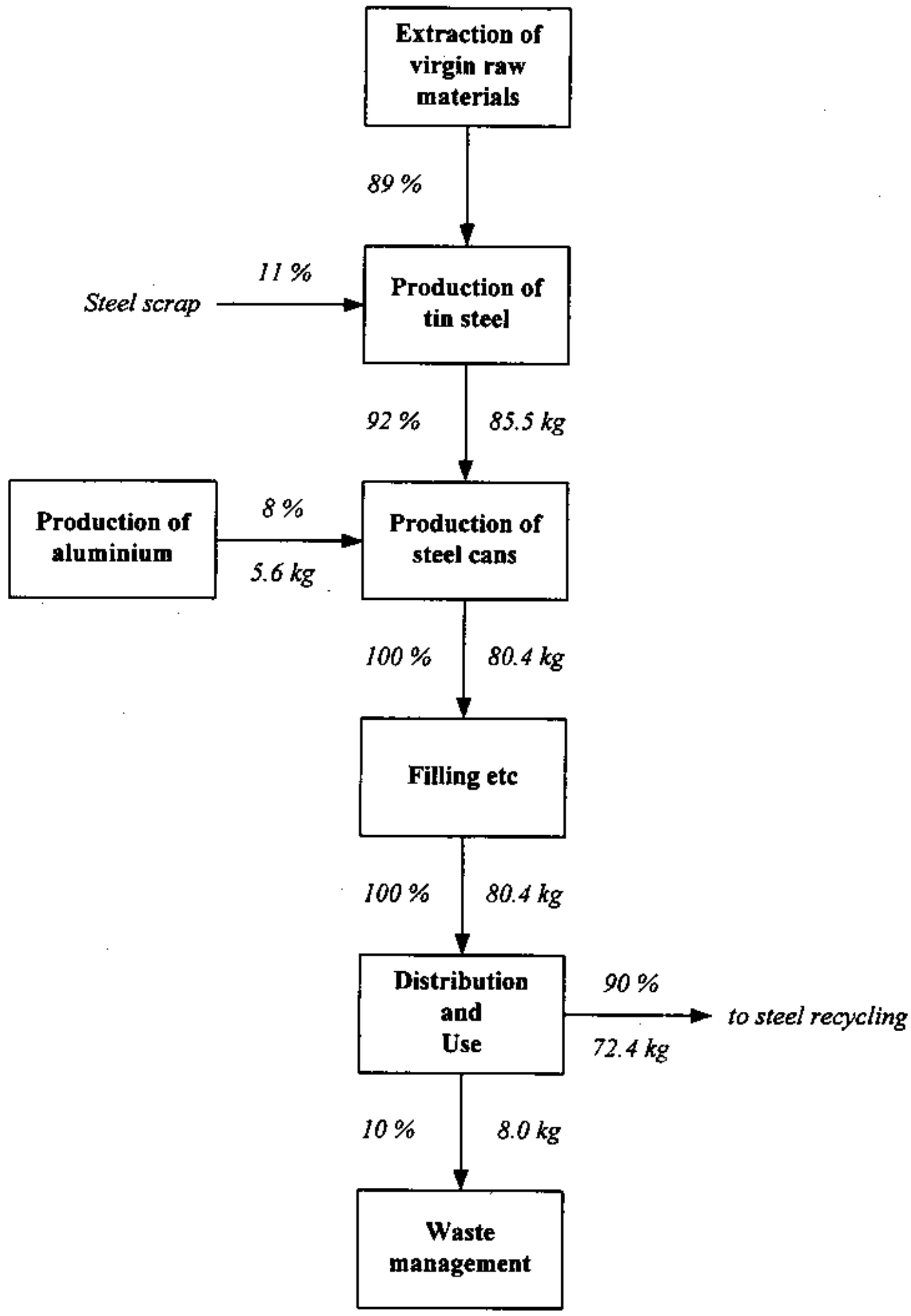

Figure 6.2
Flows of 50 cl steel can system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure. The mass balances do not add up due to material losses etc. that are not presented in the figure.

Table 6.4

System parameters for the packaging system with 50 cl steel cans. The mass presented refers to the weight of a single item, i.e., one can or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of return	Material to recycling	Material to disposal
Primary packaging	Steel can (50 cl)	40.20	100 %	Steel/Al	0 %	90 %	10 %
Secondary packaging	Tray (24 cans)	120	50 %	Corrugated board	0 %	20 %	80 %
	Foil for tray (24 cans)	20	33 %	LDPE	0 %	0 %	100 %
	Box (24 cans)	250	17 %	Corrugated board	0 %	20 %	80 %
	Box (6 cans)	60	25 %	Cardboard	0 %	20 %	80 %
	Hi-cone	3.4	25 %	LDPE	0 %	0 %	100 %
Transport packaging	Pallet (1848 cans)	22000	100 %	Wood	95 %	0 %	5 %
	Plastic ligature (1848 cans)	20	75 %	LDPE	0 %	70 %	30 %
	Glue	2	25 %	Casein/urea/H_2O	0 %	0 %	100 %

Energy demand

An explanation of the disaggregation made in Table 6.5 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 6.5

Energy demand at final use for the packaging system with 50 cl steel cans. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	2.57E+02	-2.20E+01	2.35E+02
Electricity, coal marginal	*kWh*	*2.56E+02*	*-2.20E+01*	*2.33E+02*
Fossil fuel, total	MJ	3.44E+03	-1.87E+03	1.58E+03
Coal, feedstock	*MJ*	*2.94E-02*	*-1.48E+03*	*-1.48E+03*
Diesel, heavy & medium truck (highway)	*MJ*	*1.65E+02*	*1.55E+01*	*1.81E+02*
Diesel, heavy & medium truck (rural)	*MJ*	*8.43E+01*	*0*	*8.43E+01*
Diesel, heavy & medium truck (urban)	*MJ*	*8.19E+01*	*-2.94*	*7.89E+01*
Diesel, ship (4-stroke)	*MJ*	*2.06E+01*	*-2.74*	*1.78E+01*
Fuel oil, ship (2-stroke)	*MJ*	*1.34E+02*	*-8.07E+01*	*5.29E+01*
Hard coal, feedstock	*MJ*	*1.62E+03*	*-2.53E+01*	*1.59E+03*
Natural gas (<100 kW)	*MJ*	*0*	*1.31E+01*	*1.31E+01*
Natural gas (>100 kW)	*MJ*	*8.28E+02*	*-6.83E+01*	*7.60E+02*
Natural gas	*MJ*	*3.31E+01*	*0*	*3.31E+01*
Natural gas, feedstock	*MJ*	*9.59E+01*	*0*	*9.59E+01*
Oil	*MJ*	*1.44E+01*	*0*	*1.44E+01*
Oil, feedstock	*MJ*	*9.85E+01*	*0*	*9.85E+01*
Oil, heavy fuel	*MJ*	*9.67E+01*	*-2.63E+01*	*7.04E+01*
Oil, heavy, feedstock	*MJ*	*8.65E+01*	*-4.25E+01*	*4.41E+01*
Oil, light fuel	*MJ*	*3.11E+01*	*-1.34E+02*	*-1.03E+02*
Renewable fuel, total	MJ	1.27E+01	-1.63	1.11E+01
Bark	*MJ*	*1.27E+01*	*-1.63*	*1.11E+01*
Heat etc., total	MJ	-4.53	1.16E+02	1.12E+02
BF-gas	*MJ*	*0*	*4.39E+01*	*4.39E+01*
Coke oven gas	*MJ*	*0*	*7.17E+01*	*7.17E+01*
Total energy	**MJ**	**4.38E+03**	**-1.83E+03**	**2.54E+03**

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 6.6. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 4.

Table 6.6

Inventory results for the packaging system with 50 cl steel cans. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Bauxite	g	2.56E+04	-4.47E+03	2.11E+04
Brown coal	g	2.43E+03	-2.83E+02	2.15E+03
Coal	g	2.21E+02	-1.19E+01	2.09E+02
Coal, feedstock	g	6.55E+02	-1.14E+02	5.41E+02
Crude oil	g	2.74E+04	-8.49E+03	1.89E+04
Crude oil, feedstock	g	5.64E+03	-5.53E+02	5.09E+03
Hard coal	g	2.41E+05	-1.63E+04	2.25E+05
Hydro power-water	g	2.70E+10	-5.62E+09	2.13E+10
Iron ore, 10% Fe	g	7.41E+05	-6.88E+05	5.27E+04
Land use	m²•year	2.56E+02	3.60E+01	2.92E+02
Limestone	g	2.51E+04	-2.23E+04	2.86E+03
NaCl	g	2.42E+01	-3.40E-02	2.41E+01
Natural gas	g	1.99E+04	-1.67E+03	1.82E+04
Natural gas, feedstock	g	2.04E+03	0	2.04E+03
Salt	g	3.79E+02	-6.60E+01	3.13E+02
Softwood	g	7.02E+01	-4.63	6.55E+01
Tin	g	1.80E+02	0	1.80E+02
Water	g	4.97E+07	-3.21E+06	4.65E+07
Non-elementary inflows				
Alloys	g	4.28E+02	1.01E+01	4.38E+02
Alum	g	4.57E+01	-7.36	3.83E+01
Aluminium hydroxide	g	8.19E+01	-1.43E+01	6.76E+01
Bark	g	7.46E+02	-9.60E+01	6.51E+02
BF-additives	g	2.74E+03	-2.55E+03	1.92E+02
Bottom coat	g	3.56E+01	0	3.56E+01
$Ca(OH)_2$	g	3.76E+02	0	3.76E+02
$CaCO_3$	g	3.83E+01	-6.17	3.21E+01
Calcium fluoride	g	1.78E+02	-3.10E+01	1.47E+02
CaO	g	7.02E+02	-5.74E+02	1.28E+02
Carbon	g	2.15E+02	-3.75E+01	1.77E+02
Coke	g	6.08E+02	-5.64E+02	4.35E+01

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	Unit	Packaging system	Effects on other product systems	Total
Defoamer	g	1.53E+01	-2.19	1.31E+01
Glue	g	4.17E+01	0	4.17E+01
H_2SO_4	g	1.63E+02	-2.63E+01	1.37E+02
Mobility enhance	g	4.32E+01	0	4.32E+01
Na_2SO_4	g	6.05E+01	-9.75	5.08E+01
Na_2CO_3	g	2.40E+01	-3.38	2.06E+01
NaOH	g	2.14E+02	-1.45E+01	2.00E+02
NH_3	g	1.01E+01	0	1.01E+01
Oil	g	2.57E+02	0	2.57E+02
Oxygen	m^3	0	7.90E+01	7.90E+01
Packaging	g	2.32E+02	0	2.32E+02
Paper	g	1.30E+02	0	1.30E+02
Peat	g	2.45E+02	-1.04E+01	2.35E+02
Plastic ligature	g	1.62E+01	0	1.62E+01
Polyester for strips	g	1.69E+01	0	1.69E+01
Printing ink	g	9.56E+01	0	9.56E+01
Refractory materials	g	6.02E+01	-1.05E+01	4.97E+01
Retention agents	g	2.57E+01	-3.38	2.24E+01
Rubber for tightening	g	1.45E+02	0	1.45E+02
Sizing agents	g	6.73E+01	-5.18	6.22E+01
Starch	g	8.72E+01	4.92E+01	1.36E+02
Steel	g	4.27E+01	-7.46	3.53E+01
Sulphur	g	3.42E+02	-3.98E-01	3.42E+02
Sulphuric acid	g	2.06E+02	-3.59E+01	1.70E+02
Wim-lubricant	g	6.00E+01	0	6.00E+01
Wood for pallets and frames	g	1.01E+02	0	1.01E+02
Emissions to air				
CH_4	g	1.89E+03	-1.12E+02	1.78E+03
CO	g	2.00E+03	-1.31E+03	6.84E+02
CO_2	g	5.05E+05	-1.86E+05	3.19E+05
HC	g	6.72E+01	-1.43	6.58E+01
HCl	g	2.15E+01	-5.21	1.63E+01
NMVOC	g	8.93E+01	-2.55E+01	6.38E+01
NMVOC, diesel engines	g	5.32E+01	-4.81	4.84E+01
NMVOC, electricity-coal	g	4.26	-3.68E-01	3.89
NMVOC, oil combustion	g	7.32E+01	-3.43E+01	3.89E+01
NMVOC, power plants	g	3.57	-2.36E-01	3.34
NO_x	g	1.55E+03	-3.35E+02	1.21E+03
SO_2	g	1.14E+03	-3.45E+02	8.00E+02
VOC, diesel engines	g	5.05	-3.41E-01	4.71

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	Unit	Packaging system	Effects on other product systems	Total
Emissions to water				
BOD	g	1.48E+01	-1.21E-03	1.48E+01
BOD-5	g	7.89E+01	-1.17E+01	6.72E+01
COD	g	2.77E+02	-3.26E+01	2.44E+02
Tot-P	g	1.28	0	1.28
Waste				
Bulk waste, total	g	2.47E+05	-8.44E+04	1.63E+05
Elementary waste, corrugated board	g	*-6.20E+02*	*2.43E+02*	*-3.77E+02*
Waste	g	*7.48E+04*	*-6.93E+04*	*5.49E+03*
Waste, bulky	g	*7.80E+04*	*-6.04E+03*	*7.19E+04*
Waste, combustible	g	*1.33E+02*	*0*	*1.33E+02*
Waste, industrial	g	*4.77E+04*	*-5.61E+03*	*4.21E+04*
Waste, inert residues	g	*7.63E+02*	*-1.33E+02*	*6.30E+02*
Waste, inorganic sludges	g	*1.99E+02*	*-3.12E+01*	*1.68E+02*
Waste, other rejects	g	*1.69E+02*	*3.56E+01*	*2.05E+02*
Waste, red mud	g	*7.42E+03*	*-1.30E+03*	*6.12E+03*
Waste, rubber	g	*8.87E-02*	*-5.98E-03*	*8.27E-02*
Waste, wood	g	*4.82E+02*	*0*	*4.82E+02*
Hazardous waste, total	g	8.94E+03	-5.81E+02	8.36E+03
Waste, emulsions	g	*1.68E+02*	*0*	*1.68E+02*
Waste, hazardous	g	*8.66E+03*	*-5.81E+02*	*8.08E+03*
Waste, oil	g	*3.02E+01*	*-2.38E-01*	*2.99E+01*
Waste, solvent	g	*8.06E+01*	*0*	*8.06E+01*
Slags & ashes, total	g	6.13E+03	-1.94E+01	6.12E+03
Waste, ashes (Fe_3O_4)	g	*2.07E+03*	*0*	*2.07E+03*
Waste, ashes	g	*1.04E+02*	*1.25E+02*	*2.29E+02*
Waste, slags & ashes (energy prod.)	g	*1.42E+03*	*-1.14E+02*	*1.30E+03*
Waste, slags & ashes	g	*1.35E+03*	*-9.81E+02*	*3.64E+02*
Waste, slags	g	*1.20E+03*	*9.51E+02*	*2.15E+03*
Nuclear waste, total	g	1.50E+01	1.30	1.63E+01
Waste, highly radioactive	g	*1.45E+01*	*1.35*	*1.59E+01*
Waste, radioactive	g	*4.63E-01*	*-4.85E-02*	*4.15E-01*
Co-products				
Benzene	g	2.99E+02	-2.81E+02	1.89E+01
Biogas	g	-5.82E+01	2.28E+01	-3.54E+01
Carbon reused as fuel	g	1.16E+02	-2.03E+01	9.60E+01

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	Unit	Packaging system	Effects on other product systems	Total
Corrugated board (from layer pads)	g	1.08E+02	0	1.08E+02
Dust	g	5.14E+03	-6.79E+02	4.46E+03
Glue	g	4.17E+01	0	4.17E+01
Iron(II)sulphate	g	1.40E+03	0	1.40E+03
Iron oxide	g	1.37E+02	0	1.37E+02
Mill scale	g	0	-2.98E+01	-2.98E+01
Oil	g	4.28E+01	0	4.28E+01
Plastic ligature	g	1.14E+01	0	1.14E+01
Refractories	g	0	1.18E+02	1.18E+02
Skimmings and dross for recycling	g	8.40E+01	-1.47E+01	6.94E+01
Slag	g	3.05E+04	-1.74E+04	1.31E+04
Steel scrap	g	4.27E+01	-7.46	3.53E+01
Tar	g	9.16E+02	-8.76E+02	3.91E+01
Tin hydroxide sludge	g	3.42E+01	0	3.42E+01

6.3 Impact assessment

This section presents results from the impact assessment of packaging systems with steel cans. The most important characterisation calculations and results are presented in Tables 6.7 and 6.8. For a full presentation of the classification and characterisation, we refer to Technical report 4.

Normalisation results are presented in Tables 6.9 and 6.10. Weighting results are presented in Tables 6.11 and 6.12.

Table 6.7
Classification and characterisation of the packaging system with 33 cl steel cans. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NO_x	1.35E-03	2.59	-5.65E-01	2.03
Emissions to water				
Tot-P	3.20E-02	4.58E-02	0	4.58E-02
Total		**2.66**	**-5.72E-01**	**2.09**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	1.63E-02	-1.31E-03	1.50E-02
CO	3.00E-05	7.22E-02	-4.56E-02	2.66E-02
HC	6.00E-04	4.85E-02	-1.42E-03	4.70E-02
NMVOC	4.00E-04	3.90E-02	-1.42E-02	2.48E-02
NMVOC, diesel engines	6.00E-04	3.64E-02	-3.06E-03	3.34E-02
NMVOC, electricity-coal	8.00E-04	4.58E-03	-5.23E-04	4.06E-03
NMVOC, oil combustion	3.00E-04	2.60E-02	-1.18E-02	1.42E-02
NMVOC, power plants	5.00E-04	2.22E-03	-1.94E-04	2.03E-03
VOC, diesel engines	6.00E-04	3.79E-03	-3.40E-04	3.45E-03
Total		**2.50E-01**	**-7.90E-02**	**1.71E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	2.44E-02	-5.95E-03	1.84E-02
NO_x	7.00E-04	1.34	-2.93E-01	1.05
SO_2	1.00E-03	1.48	-4.36E-01	1.05
Total		**2.88**	**-7.40E-01**	**2.14**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	5.82E+01	-4.68	5.35E+01
CO	2.00E-03	4.82	-3.04	1.77
CO_2	1.00E-03	6.26E+02	-2.28E+02	3.99E+02
N_2O	3.20E-01	1.26	-2.51E-01	1.01
Total		**6.91E+02**	**-2.36E+02**	**4.55E+02**

Table 6.8

Classification and characterisation of the packaging system with 50 cl steel cans. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NO_x	1.35E-03	2.09	-4.53E-01	1.64
Emissions to water				
Tot-P	3.20E-02	4.11E-02	0	4.11E-02
Total		**2.15**	**-4.58E-01**	**1.69**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	1.32E-02	-7.87E-04	1.25E-02
CO	3.00E-05	5.99E-02	-3.93E-02	2.05E-02
HC	6.00E-04	4.03E-02	-8.57E-04	3.95E-02
NMVOC	4.00E-04	3.57E-02	-1.02E-02	2.55E-02
NMVOC, diesel engines	6.00E-04	3.19E-02	-2.89E-03	2.90E-02
NMVOC, electricity-coal	8.00E-04	3.41E-03	-2.94E-04	3.12E-03
NMVOC, oil combustion	3.00E-04	2.20E-02	-1.03E-02	1.17E-02
NMVOC, power plants	5.00E-04	1.79E-03	-1.18E-04	1.67E-03
VOC, diesel engines	6.00E-04	3.03E-03	-2.05E-04	2.83E-03
Total		**2.12E-01**	**-6.54E-02**	**1.47E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	1.89E-02	-4.59E-03	1.43E-02
NO_x	7.00E-04	1.08	-2.35E-01	8.50E-01
SO_2	1.00E-03	1.14	-3.45E-01	8.00E-01
Total		**2.27**	**-5.88E-01**	**1.68**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	4.73E+01	-2.81	4.45E+01
CO	2.00E-03	3.99	-2.62	1.37
CO_2	1.00E-03	5.05E+02	-1.86E+02	3.19E+02
Total		**5.58E+02**	**-1.92E+02**	**3.66E+02**

Table 6.9

Normalisation results for the packaging system with 33 cl steel cans. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	7.94E-02	-2.71E-02	5.23E-02
Photochemical ozone formation (POCP)	20	1.25E-02	-3.95E-03	8.54E-03
Acidification (AP)	124	2.32E-02	-5.97E-03	1.72E-02
Nutrient enrichment (NP)	298	8.92E-03	-1.92E-03	7.00E-03
Waste				
Bulk waste (non-hazardous)	1350	1.84E-01	-7.15E-02	1.13E-01
Hazardous waste	20.7	5.13E-01	-4.64E-02	4.67E-01
Slag and ashes	320	2.09E-02	7.91E-04	2.17E-02
Nuclear waste	0.159	1.04E-01	1.50E-02	1.19E-01
Resources				
Oil	590	6.87E-02	-1.99E-02	4.88E-02
Coal	570	3.26E-01	-2.93E-02	2.96E-01
Brown coal	250	1.20E-02	-1.62E-03	1.03E-02
Natural gas	310	8.26E-02	-8.40E-03	7.42E-02
Aluminium	3.1	3.14	-5.48E-01	2.59
Iron	100	8.25E-01	-7.71E-01	5.44E-02
Tin	0.04	5.00	0	5.00

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 6.10

Normalisation results for the packaging system with 50 cl steel cans. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	6.41E-02	-2.20E-02	4.21E-02
Photochemical ozone formation (POCP)	20	1.06E-02	-3.27E-03	7.33E-03
Acidification (AP)	124	1.83E-02	-4.74E-03	1.35E-02
Nutrient enrichment (NP)	298	7.21E-03	-1.54E-03	5.68E-03
Waste				
Bulk waste (non-hazardous)	1350	1.55E-01	-6.08E-02	9.42E-02
Hazardous waste	20.7	4.32E-01	-2.81E-02	4.04E-01
Slag and ashes	320	1.75E-02	-5.55E-05	1.75E-02
Nuclear waste	0.159	9.42E-02	8.18E-03	1.02E-01
Resources				
Oil	590	5.60E-02	-1.53E-02	4.07E-02
Coal	570	2.60E-01	-1.77E-02	2.42E-01
Brown coal	250	9.74E-03	-1.13E-03	8.61E-03
Natural gas	310	7.08E-02	-5.38E-03	6.54E-02
Aluminium	3.1	2.08	-3.62E-01	1.71
Iron	100	7.41E-01	-6.88E-01	5.27E-02
Tin	0.04	4.51	0	4.51

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 6.11
Weighting results for the packaging system with 33 cl steel cans. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	1.03E-01	-3.52E-02	6.80E-02
Photochemical ozone formation (POCP)	1.2	1.50E-02	-4.74E-03	1.02E-02
Acidification (AP)	1.3	3.02E-02	-7.75E-03	2.24E-02
Nutrient enrichment (NP)	1.2	1.07E-02	-2.30E-03	8.40E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	2.03E-01	-7.87E-02	1.24E-01
Hazardous waste	1.1	5.64E-01	-5.11E-02	5.13E-01
Slag and ashes	1.1	2.30E-02	8.70E-04	2.39E-02
Nuclear waste	1.1	1.14E-01	1.65E-02	1.31E-01
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	1.58E-03	-4.57E-04	1.12E-03
Coal	5.80E-03	1.89E-03	-1.70E-04	1.72E-03
Brown coal	2.60E-03	3.11E-05	-4.22E-06	2.69E-05
Natural gas	1.60E-02	1.32E-03	-1.34E-04	1.19E-03
Aluminium	5.10E-03	1.60E-02	-2.80E-03	1.32E-02
Iron	8.50E-03	7.01E-03	-6.55E-03	4.62E-04
Tin	3.70E-02	1.85E-01	0	1.85E-01

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

Table 6.12

Weighting results for the packaging system with 50 cl steel cans. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	$[PET_{WDK2000}/PE_{WDK90}]$ (1)	$[PET_{WDK2000}]$	$[PET_{WDK2000}]$	$[PET_{WDK2000}]$
Global warming (GWP)	1.3	8.33E-02	-2.86E-02	5.47E-02
Photochemical ozone formation (POCP)	1.2	1.27E-02	-3.92E-03	8.79E-03
Acidification (AP)	1.3	2.38E-02	-6.16E-03	1.76E-02
Nutrient enrichment (NP)	1.2	8.65E-03	-1.84E-03	6.81E-03
Waste	$[PET_{WDK2000}/PE_{WDK90}]$	$[PET_{WDK2000}]$	$[PET_{WDK2000}]$	$[PET_{WDK2000}]$
Bulk waste (non-hazardous)	1.1	1.71E-01	-6.69E-02	1.04E-01
Hazardous waste	1.1	4.75E-01	-3.09E-02	4.44E-01
Slag and ashes	1.1	1.93E-02	-6.10E-05	1.92E-02
Nuclear waste	1.1	1.04E-01	9.00E-03	1.13E-01
Resources	$[PR_{W90}/PE_{WDK90}]$	$[PR_{W90}]$ (2)	$[PR_{W90}]$	$[PR_{W90}]$
Oil	2.30E-02	1.29E-03	-3.52E-04	9.36E-04
Coal	5.80E-03	1.51E-03	-1.02E-04	1.40E-03
Brown coal	2.60E-03	2.53E-05	-2.95E-06	2.24E-05
Natural gas	1.60E-02	1.13E-03	-8.61E-05	1.05E-03
Aluminium	5.10E-03	1.06E-02	-1.85E-03	8.74E-03
Iron	8.50E-03	6.30E-03	-5.85E-03	4.48E-04
Tin	3.70E-02	1.67E-01	0	1.67E-01

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

6.4 Interpretation

Important impacts

The packaging systems with steel cans contribute most to the following non-toxicological environmental impacts (see Tables 6.9-6.12):

- global warming (GWP), and
- acidification (AP)

Waste and resources

The steel can systems contribute a relatively large share (>100 mPET) of the target levels for generation of bulk waste, hazardous waste and nuclear waste. They also contribute significantly (to more than approximately 1 mPR) to the depletion of coal, natural gas, aluminium and tin resources.

Important processes

The most important processes for the environmental impacts of the 33 cl steel can system are presented in table 6.13.

Table 6.13
The most important processes of the 33 cl steel can system. The figures are given in % of the net total potential environmental impact.

	GWP	POCP	AP	NP
1. Steel can production	77	60	39	39
11. Trp of iron to tinplate production			14	15
12. Primary aluminium production	46	27	54	39
53. Distribution of beverage		21		12
66. Avoided steel production	-37	-33	-22	-19

Steel can production

The largest contributions to GWP and POCP are caused by the production of steel cans. (The process *Steel can production* includes aggregated data for a group of processes, of which tinplate production and can production are the most important ones). The main contributing parameters are carbon dioxide emissions (GWP) and carbon monoxide emissions (POCP). The production of steel cans also contributes significantly to AP and NP, mainly caused by emissions of NO_x (AP and NP) and SO_2 (AP).

Primary aluminium production

The largest contributions to AP and NP are caused by emissions of NO_x (AP and NP) and SO_2 (AP) from the production of primary aluminium. The production of primary aluminium also contributes significantly to GWP and POCP, mainly due to carbon dioxide emissions (GWP) and carbon monoxide emissions (POCP).

Distribution of beverage

The distribution of beverage contributes significantly to photochemical oxidant creation (POCP) caused by emissions of NMVOC and NMVOC from diesel engines.

Avoided steel production

The avoided steel production mainly contributes to avoided impacts for GWP, POCP and AP. The avoided impacts are caused by avoided carbon dioxide emissions (GWP), avoided carbon monoxide emissions (POCP), and avoided emissions of SO_2 and NO_x (AP).

Waste generation

The bulk waste consists mainly of industrial waste and unspecified bulk waste. The industrial waste is generated at Steel can production. The unspecified bulk waste is generated at steel can production (i.e. at the tinplate production and/or at the can production) and at primary aluminium production. The hazardous waste consists mainly of unspecified, hazardous waste and is generated at steel can production. The nuclear waste consists mainly of highly radioactive waste and is generated at the production of oil and diesel.

Resource demand

Most of the coal is used as coke at the production of pig iron in the blast furnace. A significant amount is also used for production of the electricity that is used for primary aluminium production. The natural gas is mainly used at the production of steel cans where it serves as a fuel. The depletion of aluminium (i.e. the resource bauxite) arises from the production of primary aluminium. The primary aluminium is used for the lid production. The depletion of the tin arises from the extraction of tin ore. The tin is used as an alloy in the can body.

Electricity production

The electricity production is important for the results of this LCA. In the base case scenario, electricity production is responsible for more than half of the net CO_2 emissions and approximately half of the SO_2 and NO_x emissions.

Sensitivity analyses

Sensitivity analyses were carried through as described in section 2.13. The quantitative results are presented in Table 6.14.

Table 6.14

Results from the quantitative sensitivity analyses made of the packaging system with 33 cl steel can. Functional unit: packaging and distribution of 1000 litres.

Parameters	Base case [g/1000 l beverage]	Can weight (+ 20 %) [% of base case]	Distribution (light truck) [% of base case]	Allocation method: 50/50 [% of base case]	Amount of inside coating [% of base case]	Electricity, Natural gas marginal [% of base case]	Electricity, fragmented markets [% of base case]	Electricity, European base load [% of base case]
CO_2	3,36E+05	110	103	122	102	76	99	73
SO_2	7,98E+02	106	101	116	101	60	98	169
NO_x	1,25E+03	108	109	112	101	73	99	83
VOC, total	2,77E+02	109	114	110	102	89	100	115

Can weight

The can weight is 28.2 g in the base case. This could be compared to 28.4 g in the previous study. A sensitivity scenario corresponding to an increase of the can weight by 20 % (33.8 g) was performed. The results for some important inventory parameters are shown in table 5.3. The results are increased between 6 and 10%.

Distribution of beverage

The transport data used in the distribution of beverage represent a mix of different modes of conveyance. A sensitivity analysis regarding the distribution of beverage was performed using data for distribution by light trucks. The mode of conveyance appeared to be of minor importance, especially for CO_2 and SO_2 (table 5.3).

Allocation methods

In the base-case, the recycled steel is assumed to replace the same amount of virgin steel in new products. A sensitivity analysis was performed where the recycled steel is assumed to replace equal amounts of virgin steel and recycled steel from other products. The results for some inventory parameters are shown in table 5.3.

Amount of inside coatings

The amounts of inside coatings differ between the cans that are used for beer and those that are used for soft drinks (the amount is larger in the soft drink cans). In the base-case, an average between these amounts was used. A sensitivity analysis was performed where the amount of inside coatings was increased to the amount used for soft drink cans. The amount of inside coatings appeared to be of minor importance (see table 5.3).

Electricity production

The electricity data used in the base-case is coal marginal. Three sensitivity analyses were performed for electricity production (natural gas marginal, fragmented markets and European base load). It is clear from the results (table 5.3) that the assumption regarding the electricity production is important.

Data gaps and omissions

The analysis did not include the production of a large number of ancillary materials. The most important non-elementary inflows are alloys (other than tin) used at tinplate production and sulphur used at sulphuric acid (H_2SO_4) production.

Production of materials for secondary packagings (trays, boxes etc.) and pallets is included in the LCA, but the actual packaging production - conversion, nailing etc. - is not included.

The environmental impacts of the retailer and the private transport home from the retailer were not included in this study. For steel cans, these impacts are insignificant (see Technical report 4).

Uncertainties

The data used for steel can production are aggregated data for a group of processes, of which tinplate production and can production are the most important ones. Altogether, we estimate these data to be fairly representative and complete. The uncertainty of these data is estimated to be medium. The data used for primary aluminium production are EAA data, with fair representativity, good completeness and medium uncertainty. The data used for (avoided) steel production are APEAL data, with fair representativity and completeness as well as medium uncertainty. The data used for distribution of the beverage are assessed to have medium uncertainty and good completeness and representativity.

For further details, se Technical report 4.

7 Refillable PET bottles

7.1 The systems

50 cl bottle

The process tree of the packaging system is illustrated in Figure 7.1. The 50 cl refillable PET bottle is produced from preforms in turn produced from polyethylene terephthalate (PET). To distribute 1000 litres of beverage 2000 50 cl PET bottles (1000/0.50) are required. The weight of one 50 cl refillable PET bottle is 53 g.

150 cl bottle

The process tree of the packaging system is illustrated in Figure 7.2. The 150 cl refillable PET bottle is produced from preforms in turn produced from polyethylene terephthalate (PET). To distribute 1000 litres of beverage 667 150 cl PET bottles (1000/1.50) are required. The weight of one 150 cl refillable PET bottle is 105 g.

Recycling rates

Most of the used bottles (98.5%) are collected for recycling (see Tables 7.1 and 7.4). The remaining 1.5% end up in waste incineration where energy is recovered. A small share (3.5%) are discarded at the washing and filling processes. The discarded bottles are recycled into other systems where the material displaces 50% virgin raw materials and 50% recycled PET (see section 2.7.5).

7.2 Inventory analysis

7.2.1 50 cl refillable PET bottle

Input data

The bottle, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 7.1. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 5. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

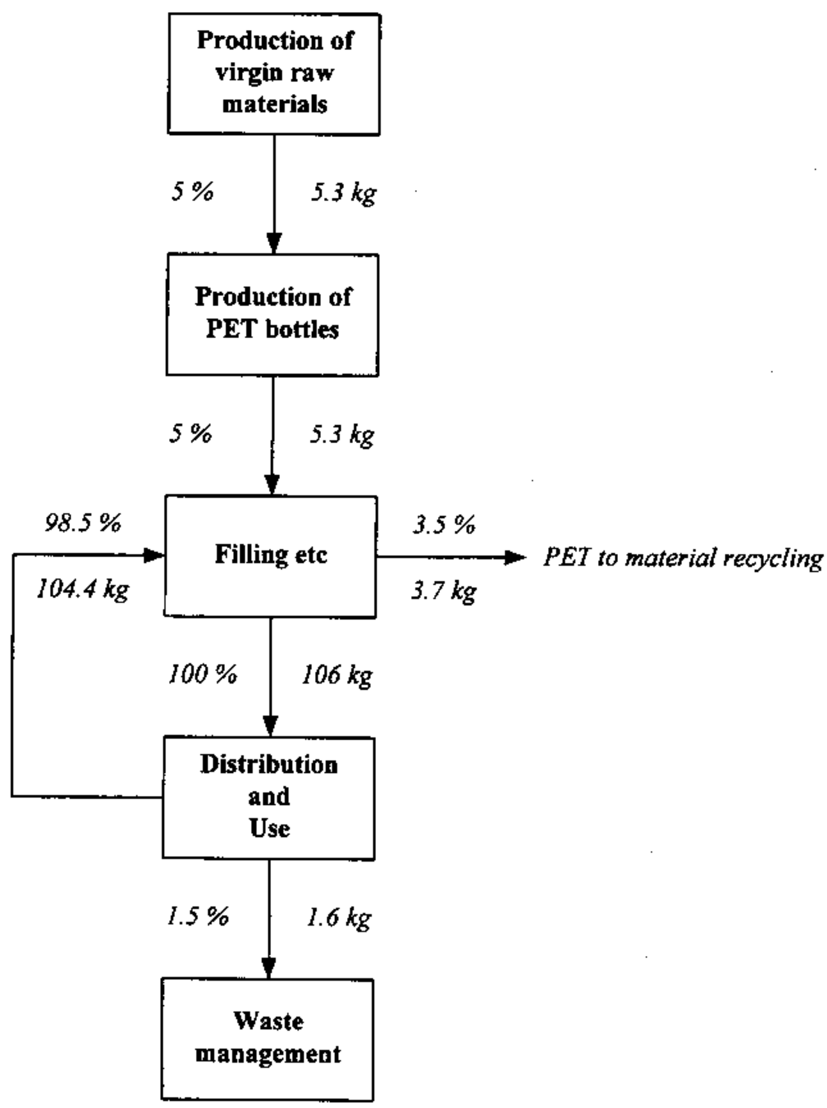

Figure 7.1
Flows of 50 cl refillable PET bottle system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure.

Table 7.1
System parameters for the packaging system with 50 cl refillable PET bottles. The mass presented refers to the weight of a single item, i.e., one bottle or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of reuse	Material to recycling	Material to disposal
Primary packaging	PET bottle (50 cl)	53	100 %	PET	95 %	3.5 %	1.5 %
	Cap	2.0	100 %	PP	0 %	85 %	15 %
	Insert	0.2	100 %	LDPE	0 %	85 %	15 %
	Label	0.6	100 %	Paper	0 %	0 %	100 %
	Glue	0.2	100 %	Casein/urea/H_2O	0 %	0 %	100 %
Secondary packaging	Crate (24 bottles)	1550	90 %	HDPE	99.4 %	0.6 %	0 %
	Tray (48 bottles)	1800	10 %	HDPE	99.4 %	0.6 %	0 %
	Multipack (6 bottles)	18	5 %	Cardboard	0 %	20 %	80 %
	Multipack (6 bottles)	15	5 %	LDPE	0 %	0 %	100 %
Transport packaging	Pallet (960 bottles)	22000	100 %	Wood	95 %	0 %	5 %
	Plastic ligature (960 bottles)	20	100 %	LDPE	0 %	70 %	30 %

Energy demand

An explanation of the disaggregation made in Table 7.2 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 7.2

Energy demand at final use for the packaging system with 50 cl refillable PET bottles. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	3.97E+01	-2.69	3.70E+01
Electricity, coal marginal	*kWh*	*3.65E+01*	*-6.15E-02*	*3.64E+01*
Fossil fuel, total	MJ	1.29E+03	-4.26E+02	8.61E+02
Coal	*MJ*	*2.93E+01*	*-1.03E+01*	*1.90E+01*
Diesel, heavy & medium truck (highway)	*MJ*	*9.75E+01*	*1.74*	*9.92E+01*
Diesel, heavy & medium truck (rural)	*MJ*	*9.55E+01*	*0*	*9.55E+01*
Diesel, heavy & medium truck (urban)	*MJ*	*8.05E+01*	*1.30E-01*	*8.06E+01*
Hard coal	*MJ*	*7.12E+01*	*0*	*7.12E+01*
Natural gas (>100 kW)	*MJ*	*1.12E+02*	*-5.02E+01*	*6.16E+01*
Natural gas	*MJ*	*1.36E+02*	*-4.78E+01*	*8.84E+01*
Natural gas, feedstock	*MJ*	*1.40E+02*	*-4.70E+01*	*9.27E+01*
Oil	*MJ*	*1.23E+02*	*-4.09E+01*	*8.17E+01*
Oil, feedstock	*MJ*	*3.93E+02*	*-1.53E+02*	*2.40E+02*

Inventory results

The resource, emissions and waste flows of the systems are presented in Table 7.3. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 5.

Table 7.3

Selection of inventory results for the packaging system with 50 cl refillable PET bottles. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Brown coal	g	2.88E+02	-3.19E+01	2.56E+02
Coal	g	1.05E+03	-3.68E+02	6.81E+02
Crude oil	g	1.02E+04	-2.93E+03	7.29E+03
Crude oil, feedstock	g	9.22E+03	-3.59E+03	5.63E+03
Hard coal	g	2.09E+04	-6.96E+01	2.08E+04
Hydro power-water	g	2.94E+09	-2.15E+04	2.94E+09
NaCl	g	5.13E+01	-1.84E+01	3.29E+01
Natural gas	g	5.08E+03	-2.01E+03	3.08E+03
Natural gas, feedstock	g	2.58E+03	-8.70E+02	1.71E+03
Surface water	g	1.31E+05	-1.90E-08	1.31E+05
Water	g	5.10E+06	2.99E+04	5.13E+06
Non-elementary inflows				
Alum	g	1.11	0	1.11
Auxiliary materials	g	1.16E+01	0	1.16E+01
Bark	g	2.58E+02	0	2.58E+02
Binders	g	9.78E+01	0	9.78E+01
$Ca(OH)_2$	g	6.12E+01	4.60E+01	1.07E+02
Corrugated board	g	3.79E+01	0	3.79E+01
Dry strength additives	g	4.15E+01	0	4.15E+01
Fillers	g	4.42E+02	0	4.42E+02
H_2SO_4	g	5.86E+01	0	5.86E+01
Ink	g	2.84E+01	0	2.84E+01
Lacquer, water	g	1.70E+01	0	1.70E+01
$NaClO_3$	g	5.65E+01	0	5.65E+01
NaOH	g	2.96E+03	0	2.96E+03
O_2	g	5.08E+01	0	5.08E+01
Other additives	g	1.74E+02	0	1.74E+02
Peat	g	6.00E+01	0	6.00E+01
Pigment	g	3.71E+01	0	3.71E+01
Steel strappings	g	0	1.11E+01	1.11E+01

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	Unit	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	g	1.88E+02	5.50E+01	2.43E+02
CO	g	2.07E+02	-1.48E+01	1.92E+02
CO_2	g	8.69E+04	-9.64E+03	7.72E+04
HC	g	2.86E+02	-9.84E+01	1.88E+02
HCl	g	4.61	-3.02E-01	4.30
N_2O	g	8.42E-01	-1.75E-02	8.24E-01
NMVOC	g	5.62E+01	-1.58E+01	4.05E+01
NMVOC, diesel engines	g	3.03E+01	1.61E-01	3.04E+01
NO_x	g	4.98E+02	-6.20E+01	4.36E+02
SO_2	g	3.50E+02	-7.42E+01	2.75E+02
Emissions to water				
Acid as H^+	g	1.34	-5.02E-01	8.43E-01
BOD	g	5.64	-1.97	3.67
BOD-5	g	1.80	-8.97E-03	1.79
BOD-7	g	1.57E+01	0	1.57E+01
COD	g	2.60E+01	-5.28	2.08E+01
Phosphate	g	1.00E-01	-4.20E-02	5.83E-02
Tot-N	g	2.18	-4.32E-01	1.75
Tot-P	g	7.98E-02	0	7.98E-02
Waste				
Bulk waste, total	g	1.58E+04	6.14E+02	1.64E+04
Elementary waste, solid	*g*	*0*	*3.63E+03*	*3.63E+03*
Waste, bulky	*g*	*6.63E+03*	*-1.12E+01*	*6.62E+03*
Waste, industrial	*g*	*6.98E+03*	*-2.96E+03*	*4.02E+03*
Waste, mineral	*g*	*7.14E+02*	*-8.17E+01*	*6.33E+02*
Waste, paper	*g*	*5.97E+02*	*0*	*5.97E+02*
Waste, paper production	*g*	*1.76E+02*	*0*	*1.76E+02*
Waste, PP	*g*	*1.84E+02*	*0*	*1.84E+02*
Glue to waste water treatment plant	*g*	*4.00E+02*	*0*	*4.00E+02*
Hazardous waste, total	g	1.05E+03	-3.80E+02	6.69E+02
Waste, hazardous	*g*	*1.05E+03*	*-3 80E+02*	*6.66E+02*
Slags & ashes, total	g	5.10E+02	2.48E+01	5.35E+02
Waste, slags & ashes (energy prod.)	*g*	*1.79E+02*	*-3.04E-01*	*1.78E+02*
Waste, slags & ashes	*g*	*2.53E+02*	*5.23E+01*	*3.05E+02*
Nuclear waste, total	g	8.69	7.44E-02	8.76
Waste, highly radioactive	*g*	*8.65*	*7.44E-02*	*8.73*

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	Unit	Packaging system	Effects on other product systems	Total
Waste, radioactive	*g*	*3.54E-02*	*-6.02E-05*	*3.53E-02*
Co-products				
Multipac-CB	g	5.98E+01	0	5.98E+01
Paper, fuel	g	1.96E+02	0	1.96E+02
Paper, recycling	g	1.00E+02	0	1.00E+02
Plastic ligature	g	2.92E+01	0	2.92E+01
Tall oil	g	5.32E+01	0	5.32E+01

7.2.2 150 cl refillable PET bottles

Input data

The bottle, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 7.4. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 5. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

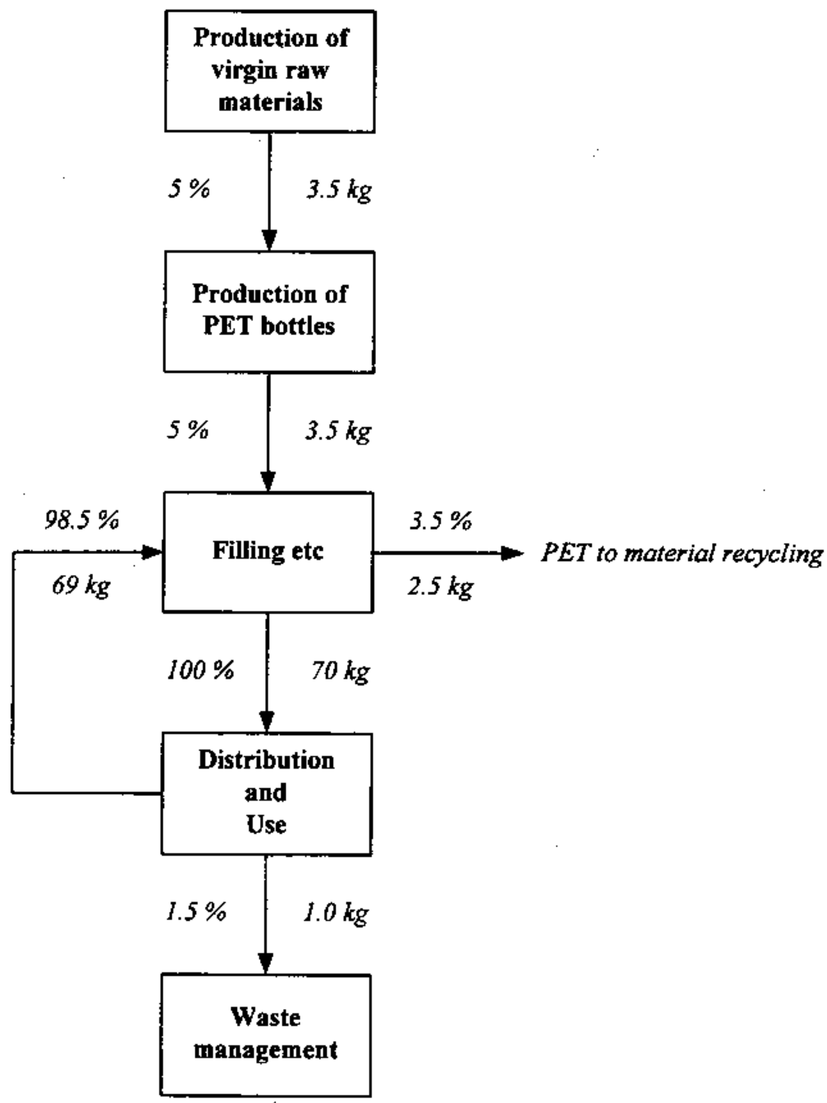

Figure 7.2
Flows of 150 cl refillable PET bottle system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure.

Table 7.4

System parameters for the packaging system with 150 cl refillable PET bottles. The mass presented refers to the weight of a single item, i.e., one can or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of reuse	Material to recycling	Material to disposal
Primary packaging	PET bottle (150 cl)	105	100 %	PET	95 %	3.5 %	1.5 %
Caps	Cap	2.0	100 %	PP	0 %	85 %	15 %
	Insert	0.2	100 %	LDPE	0 %	85 %	15 %
Labels	Label	0.8	100 %	Paper	0 %	0 %	100 %
	Glue	0.3	100 %	Casein/urea/H_2O	0 %	0 %	100 %
Secondary packaging	Crate (11 bottles) [(1)]	2017	90 %	HDPE	99.4 %	0.6 %	0 %
	Tray (24 bottles)	1550	10 %	HDPE	99.4 %	0.6 %	0 %
	Multipack (3 bottles)	18	5 %	Cardboard	0 %	20 %	80 %
	Multipack (3 bottles)	15	5 %	LDPE	0 %	0 %	100 %
Transport packaging	Pallet (240 bottles)	22000	100 %	Wood	95 %	0 %	5 %
	Plastic ligature (240 bottles)	20	100 %	LDPE	0 %	70 %	30 %

Energy demand

An explanation of the disaggregation made in Table 7.5 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 7.5

Energy demand at final use for the packaging system with 150 cl refillable PET bottles. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	3.50E+01	-1.95	3.30E+01
Electricity, coal marginal	*kWh*	*3.38E+01*	*-6.16E-01*	*3.32E+01*
Fossil fuel, total	MJ	8.47E+02	-2.49E+02	5.98E+02
Coal	*MJ*	*1.69E+01*	*-5.81*	*1.11E+01*
Diesel, heavy & medium truck (highway)	*MJ*	*9.30E+01*	*1.15*	*9.41E+01*
Diesel, heavy & medium truck (rural)	*MJ*	*9.28E+01*	*0*	*9.28E+01*
Diesel, heavy & medium truck (urban)	*MJ*	*7.88E+01*	*6.47E-02*	*7.89E+01*
Hard coal	*MJ*	*4.73E+01*	*0*	*4.73E+01*
Natural gas (>100 kW)	*MJ*	*9.71E+01*	*-3.93E+01*	*5.78E+01*
Natural gas	*MJ*	*7.72E+01*	*-2.61E+01*	*5.12E+01*
Natural gas, feedstock	*MJ*	*7.26E+01*	*-2.34E+01*	*4.93E+01*
Oil	*MJ*	*7.32E+01*	*-2.34E+01*	*4.98E+01*
Oil, feedstock	*MJ*	*1.93E+02*	*-7.11E+01*	*1.22E+02*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 7.6. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 5.

Table 7.6
Inventory results for the packaging system with 150 cl refillable PET bottles. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Brown coal	g	2.70E+02	-2.76E+01	2.42E+02
Coal	g	6.07E+02	-2.07E+02	3.99E+02
Crude oil	g	8.80E+03	-2.10E+03	6.70E+03
Crude oil, feedstock	g	4.53E+03	-1.67E+03	2.86E+03
Hydro power-water	g	1.50E+09	-1.68E+04	1.50E+09
NaCl	g	2.66E+01	-9.12	1.75E+01
Natural gas	g	3.69E+03	-1.36E+03	2.33E+03
Surface water	g	5.76E+04	-1.97E-07	5.76E+04
Water	g	4.57E+06	-4.16E+04	4.53E+06
Non-elementary inflows				
Bark	g	3.11E+02	0	3.11E+02
Binders	g	4.30E+01	0	4.30E+01
$Ca(OH)_2$	g	6.31E+01	2.77E+01	9.08E+01
Corrugated board	g	1.67E+01	0	1.67E+01
Dry strength additives	g	1.83E+01	0	1.83E+01
H_2SO_4	g	2.67E+01	0	2.67E+01
Ink	g	1.25E+01	0	1.25E+01
$NaClO_3$	g	2.48E+01	0	2.48E+01
NaOH	g	9.68E+02	0	9.68E+02
O_2	g	2.23E+01	0	2.23E+01
Other additives	g	8.72E+01	0	8.72E+01
Peat	g	2.68E+01	0	2.68E+01
Pigment	g	1.24E+01	0	1.24E+01
SO_2	g	1.75E+01	0	1.75E+01
Emissions to air				
CH_4	g	1.75E+02	1.70E+01	1.92E+02
CO	g	1.71E+02	-1.14E+01	1.59E+02
CO_2	g	7.24E+04	-7.85E+03	6.45E+04
HC	g	1.72E+02	-5.72E+01	1.15E+02
HCl	g	3.63	-2.14E-01	3.41

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	Unit	Packaging system	Effects on other product systems	Total
N_2O	g	7.98E-01	-1.69E-02	7.81E-01
NMVOC	g	5.44E+01	-1.23E+01	4.21E+01
NMVOC, diesel engines	g	2.93E+01	8.85E-02	2.94E+01
NO_x	g	4.06E+02	-3.76E+01	3.69E+02
SO_2	g	2.37E+02	-4.40E+01	1.93E+02
Emissions to water				
Acid as H^+	g	7.68E-01	-2.77E-01	4.91E-01
BOD	g	3.65	-1.26	2.38
BOD-5	g	1.22	-7.00E-03	1.21
BOD-7	g	6.90	0	6.90
COD	g	1.70E+01	-3.75	1.32E+01
Tot-N	g	1.78	-3.37E-01	1.44
Tot-P	g	3.51E-02	0	3.51E-02
Waste				
Bulk waste, total	g	1.34E+04	-6.45E+02	1.27E+04
Elementary waste, solid	*g*	*0*	*1.80E+03*	*1.80E+03*
Waste, bulky	*g*	*6.13E+03*	*-1.12E+02*	*6.02E+03*
Waste, industrial	*g*	*6.13E+03*	*-2.31E+03*	*3.82E+03*
Waste, mineral	*g*	*4.54E+02*	*-4.55E+01*	*4.08E+02*
Waste, paper	*g*	*2.62E+02*	*0*	*2.62E+02*
Glue to waste water treatment plant	*g*	*2.00E+02*	*0*	*2.00E+02*
Hazardous waste, total	g	9.23E+02	-3.01E+02	6.22E+02
Waste, hazardous	*g*	*9.21E+02*	*-3.00E+02*	*6.20E+02*
Slags & ashes, total	g	4.28E+02	1.36E+01	4.42E+02
Waste, slags & ashes (energy prod.)	*g*	*1.66E+02*	*-3.02*	*1.62E+02*
Waste, slags & ashes	*g*	*2.18E+02*	*3.15E+01*	*2.49E+02*
Nuclear waste, total	g	8.22	6.11E-02	8.29
Waste, highly radioactive	*g*	*8.19*	*6.17E-02*	*8.25*
Waste, radioactive	*g*	*3.23E-02*	*-5.83E-04*	*3.17E-02*
Co-products				
Multipac-CB	g	4.00E+01	0	4.00E+01
Paper, fuel	g	8.62E+01	0	8.62E+01
Paper, recycling	g	4.40E+01	0	4.40E+01
Plastic ligature	g	3.90E+01	0	3.90E+01
Tall oil	g	2.34E+01	0	2.34E+01

7.3 Impact assessment

This section presents results from the impact assessment of packaging systems with refillable PET bottles. The most important characterisation calculations and results are presented in Tables 7.7 and 7.8. For a full presentation of the classification and characterisation, we refer to Technical report 5

Normalisation results are presented in Tables 7.9 and 7.10. Weighting results are presented in Tables 7.11 and 7.12.

Table 7.7
Classification and characterisation of the packaging system with 50 cl refillable PET bottles. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NO_x	1.35 E-03	6.72E-01	-8.37E-02	5.89E-01
Emissions to water				
Phosphate	3.20E-02	3.21E-03	-1.35E-03	1.87E-03
Tot-N	4.43E-03	9.66E-03	-1.92E-03	7.75E-03
Tot-P	3.20E-02	2.56E-03	0	2.56E-03
Total		**6.88E-01**	**-8.71E-02**	**6.01E-01**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	1.32E-03	3.85E-04	1.70E-03
CO	3.00E-05	6.20E-03	-4.45E-04	5.76E-03
HC	6.00E-04	1.72E-01	-5.90E-02	1.13E-01
NMVOC	4.00E-04	2.25E-02	-6.30E-03	1.62E-02
NMVOC, diesel engines	6.00E-04	1.82E-02	9.69E-05	1.83E-02
Total		**2.21E-01**	**-6.54E-02**	**1.56E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	4.05E-03	-2.66E-04	3.79E-03
NO_x	7.00E-04	3.49E-01	-4.34E-02	3.05E-01
SO_2	1.00E-03	3.50E-01	-7.42E-02	2.75E-01
Emissions to water				
Acid as H+	3.20E-02	4.30E-02	-1.61E-02	2.70E-02
Total		**7.46E-01**	**-1.34E-01**	**6.12E-01**

Global warming potential (GWP) [kg CO_2-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	4.70	1.38	6.08
CO	2.00E-03	4.14E-01	-2.97E-02	3.84E-01
CO_2	1.00E-03	8.69E+01	-9.64	7.72E+01
HC	3.00E-03	8.59E-01	-2.95E-01	5.63E-01
N_2O	0.32	2.69E-01	-5.59E-03	2.64E-01
Total		**9.31E+01**	**-8.59**	**8.45E+01**

Table 7.8

Classification and characterisation of the packaging system with 150 cl refillable PET bottles. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NO_x	1.35 E-03	5.48E-01	-5.07E-02	4.98E-01
Emissions to water				
Tot-N	4.43E-03	7.87E-03	-1.49E-03	6.38E-03
Tot-P	3.20E-02	1.12E-03	0	1.12E-03
Total		**5.59E-01**	**-5.28E-02**	**5.06E-01**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	1.23E-03	1.19E-04	1.34E-03
CO	3.00E-05	5.12E-03	-3.41E-04	4.77E-03
HC	6.00E-04	1.03E-01	-3.43E-02	6.90E-02
NMVOC	4.00E-04	2.18E-02	-4.92E-03	1.68E-02
NMVOC, diesel engines	6.00E-04	1.76E-02	5.31E-05	1.76E-02
Total		**1.50E-01**	**-3.95E-02**	**1.11E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	3.19E-03	-1.88E-04	3.00E-03
NO_x	7.00E-04	2.84E-01	-2.63E-02	2.58E-01
SO_2	1.00E-03	2.37E-01	-4.40E-02	1.93E-01
Emissions to water				
Acid as H^+	3.20E-02	2.46E-02	-8.86E-03	1.57E-02
Total		**5.50E-01**	**-7.94E-02**	**4.71E-01**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	4.38	4.26E-01	4.80
CO	2.00E-03	3.41E-01	-2.27E-02	3.18E-01
CO_2	1.00E-03	7.24E+01	-7.85	6.45E+01
HC	3.00E-03	5.17E-01	-1.72E-01	3.45E-01
N_2O	0.32	2.55E-01	-5.42E-03	2.50E-01
Total		**7.79E+01**	**-7.62**	**7.03E+01**

Table 7.9

Normalisation results for the packaging system with 50 cl refillable PET bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	1.07E-02	-9.88E-04	9.71E-03
Photochemical ozone formation (POCP)	20	1.11E-02	-3.27E-03	7.80E-03
Acidification (AP)	124	6.02E-03	-1.08E-03	4.94E-03
Nutrient enrichment (NP)	298	2.31E-03	-2.92E-04	2.02E-03
Waste				
Bulk waste (non-hazardous)	1350	1.14E-02	4.55E-04	1.18E-02
Hazardous waste	20.7	5.07E-02	-1.84E-02	3.23E-02
Slag and ashes	320	1.46E-03	7.09E-05	1.53E-03
Nuclear waste	0.159	5.46E-02	4.68E-04	5.51E-02
Resources				
Oil	590	3.30E-02	-1.11E-02	2.19E-02
Coal	570	2.35E-02	-4.72E-04	2.31E-02
Brown coal	250	1.15E-03	-1.28E-04	1.03E-03
Natural gas	310	2.47E-02	-9.27E-03	1.54E-02

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 7.10

Normalisation results for the packaging system with 150 cl refillable PET bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system $[PE_{WDK90}]$ (2)	Effects on other product systems $[PE_{WDK90}]$ (2)	Total $[PE_{WDK90}]$ (2)
Environmental impacts				
Global warming (GWP)	8700	8.95E-03	-8.76E-04	8.08E-03
Photochemical ozone formation (POCP)	20	7.51E-03	-1.98E-03	5.53E-03
Acidification (AP)	124	4.44E-03	-6.41E-04	3.80E-03
Nutrient enrichment (NP)	298	1.88E-03	-1.77E-04	1.70E-03
Waste				
Bulk waste (non-hazardous)	1350	9.76E-03	-4.78E-04	9.28E-03
Hazardous waste	20.7	4.46E-02	-1.45E-02	3.00E-02
Slag and ashes	320	1.22E-03	3.89E-05	1.26E-03
Nuclear waste	0.159	5.17E-02	3.84E-04	5.21E-02
Resources				
Oil	590	2.26E-02	-6.39E-03	1.62E-02
Coal	570	2.14E-02	-6.32E-04	2.08E-02
Natural gas	310	1.62E-02	-5.78E-03	1.04E-02

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 7.11

Weighting results for the packaging system with 50 cl refillable PET bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	1.39E-02	-1.28E-03	1.26E-02
Photochemical ozone formation (POCP)	1.2	1.33E-02	-3.93E-03	9.36E-03
Acidification (AP)	1.3	7.82E-03	-1.41E-03	6.42E-03
Nutrient enrichment (NP)	1.2	2.77E-03	-3.51E-04	2.42E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	1.25E-02	5.00E-04	1.30E-02
Hazardous waste	1.1	5.58E-02	-2.02E-02	3.56E-02
Slag and ashes	1.1	1.60E-03	7.80E-05	1.68E-03
Nuclear waste	1.1	6.01E-02	5.15E-04	6.06E-02
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	7.58E-04	-2.54E-04	5.04E-04
Coal	5.80E-03	1.36E-04	-2.74E-06	1.34E-04
Natural gas	1.60E-02	3.95E-04	-1.48E-04	2.47E-04

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

Table 7.12

Weighting results for the packaging system with 150 cl refillable PET bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	1.16E-02	-1.14E-03	1.05E-02
Photochemical ozone formation (POCP)	1.2	9.01E-03	-2.37E-03	6.64E-03
Acidification (AP)	1.3	5.77E-03	-8.33E-04	4.94E-03
Nutrient enrichment (NP)	1.2	2.25E-03	-2.13E-04	2.04E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	1.07E-02	-5.26E-04	1.02E-02
Hazardous waste	1.1	4.90E-02	-1.60E-02	3.30E-02
Slag and ashes	1.1	1.34E-03	4.28E-05	1.39E-03
Nuclear waste	1.1	5.69E-02	4.23E-04	5.73E-02
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	5.20E-04	-1.47E-04	3.73E-04
Coal	5.80E-03	1.24E-04	-3.66E-06	1.20E-04
Natural gas	1.60E-02	2.60E-04	-9.25E-05	1.67E-04

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

7.4 Interpretation

Important impacts

The packaging systems with refillable PET bottles contribute most to the following non-toxicological environmental impacts (see Tables 7.9-7.12):

- global warming (GWP), and
- photochemical ozone formation (POCP)

Waste and resources

The refillable PET bottle systems contribute less than 100 mPET for all waste categories and less than 1 mPR for the depletion of all resources.

Important processes

The most important processes for the environmental impacts of the 50 cl refillable PET bottle system are presented in Table 7.13.

Table 7.13
The most important processes of the 50 cl refillable PET bottle system. The figures are given in % of the net total potential environmental impact.

	GWP	POCP	AP	NP
1. PET-resin production	17	83	39	24
3. Bottle production	14		20	
4. Washing & filling	31		11	12
6. Caps & inserts production				
7. PP-production		20	14	
Trp 21. Distribution of beverage	27	26	28	48
28. PET-production (avoided)		-29	-14	

PET-resin production

The largest contribution to POCP and AP is caused by hydro carbon emissions (POCP) and emissions of SO_2 and NO_x (AP) from the PET-resin production. The production of PET-resin also contributes to NP mainly due to NO_x emissions.

Bottle production

The production of bottles mainly contributes to AP, which is caused by SO_2 emissions.

Washing & filling

The largest contribution to GWP is caused by CO_2 emissions from the washing and filling process in the brewery.

PP-production

The production of polypropylene mainly contributes to POCP, which is caused by hydro carbon emissions.

Distribution of beverage

The largest contribution NP is caused by the distribution of beverage. The main contributing parameters are emissions of NMVOC from diesel engines and NO_X. The distribution of beverage also contributes to AP, POCP and GWP, which is caused by emissions of NO_X (AP), emissions of NMVOC and NMVOC from diesel engines (POCP) and CO_2 emissions.

PET-production (avoided)

The avoided PET-production mainly contributes to avoided impacts for POCP because of avoided hydro carbon emissions.

Sensitivity analyses

Sensitivity analyses were carried through as described in section 2.13. The quantitative results are presented in Table 7.14.

Table 7.14

Results from the quantitative sensitivity analyses made on the packaging system with 50 cl refillable PET bottles. Functional unit: packaging and distribution of 1000 litres.

Parameters	Base case [g 1000 l beverage]	90 % collection rate [% of base case]	Bottle weight (+ 20 %) [% of base case]	Distribution (light truck) [% of base case]	Electricity, fragmented markets [% of base case]	Electricity, European base load average [% of base case]
CO_2	7,73E+04	156	110	119	89	83
SO_2	2,75E+02	235	113	106	86	132
NO_x	4,36E+02	155	106	131	92	93
VOC, total	5,06E+02	169	109	112	76	80

Collection rate

The collection rate is 98.5 % in the base case. A sensitivity analysis regarding the collection rate was performed. The collection rate was decreased from 98.5 % (as in the base case) to 90 %. The results for some of the important inventory parameters are shown in Table 7.14. It is clear from the results that the assumption regarding the collection rate is important.

Bottle weight

The bottle weight is 53 g in the base case. This could be compared to 52 g in the previous study. A sensitivity scenario corresponding to an increase of the bottle weight by 20 % (64 g) was performed. The results for some of the important inventory parameters are shown in Table 7.14. The bottle weight appears to be of minor importance especially since the bottle weight increase of 20 % is excessive.

Discarded bottles

An increased share of discarded bottles at the brewery (the share of discarded bottles is 3.5 % in the base case) has similar effects as the decrease of collection rate above.

Allocation methods

In the recycling of discarded PET bottles and PP caps it is assumed that 50 % of the PET and PP replaces virgin raw materials and that 50 % replaces recycled material from other products. This assumption is important for the LCA results, in particular for POCP and AP.

Use of recycled PET

If recycled PET is used in the production of PET bottles, the primary PET production in the packaging system is reduced. On the other hand, the primary PET production in other systems is likely to be increased. The net effect is still that primary production is reduced somewhat. As indicated by the dominance analysis, this could have a significant effect on the POCP and AP results.

Distribution of beverage

A sensitivity analysis regarding the distribution of beverage was performed. When using data for light truck in the distribution of beverage the environmental impacts were increased, especially concerning NO_x and CO_2 (Table 7.14).

Electricity production

The electricity data used in the base case represent coal marginal. Two sensitivity analyses were performed for electricity production (long term base load at fragmented markets and European base load average). It is clear from the results (Table 7.14) that the assumption regarding the electricity production is important.

Data gaps and omissions

The most important data gaps are:

- Lack of information concerning the process efficiencies in the production of preforms/bottles i.e. the amount of material waste is unknown.
- No information about potential water emissions in the washing and filling process.

The analysis did not include the production of a large number of ancillary materials. The most important non-elementary inflow might be sodium hydroxide (NaOH) used in the washing and filling process in the brewery. When including the production of NaOH the total energy demand in the packaging system would increase by approximately 3 % (see Technical report 5).

The production of materials for secondary packagings (multipacks), transport packaging (pallets and plastic ligature) and cap inserts is included in the LCA, but the actual packaging production - conversion, nailing etc. - is not included.

Neither does the analysis include the environmental impacts of the retailer, nor the private transport home from the retailer. These omissions affect the total energy demand of the system by approximately 1% each.

There are important data gaps in the characterisation of human toxicity in air and soil, as well as chronic terrestrial and aquatic ecotoxicity.

Uncertainties

The data quality for the two most important processes (distribution and washing & filling) is assessed to have medium uncertainty, fair completeness and good representativity.

The uncertainties in the normalisation of toxicity impacts are large. However, this does not affect the comparisons between the systems.

For further details, see Technical report 5.

8 Disposable PET bottles

8.1 The systems

50 cl bottle

The process tree of the packaging system is illustrated in Figure 8.1. The 50 cl disposable PET bottle is produced from preforms in turn produced from polyethylene terephthalate (PET). To distribute 1000 litres of beverage 2000 50 cl PET bottles (1000/0.50) are required. The weight of one 50 cl disposable PET bottle is 28 g.

150 cl bottle

The process tree of the packaging system is illustrated in Figure 8.2. The 150 cl disposable PET bottle is produced from preforms in turn produced from polyethylene terephalate (PET). To distribute 1000 litres of beverage 667 150 cl PET bottles (1000/1.50) are required. The weight of one 150 cl disposable PET bottle is 42 g.

Recycling rates

Most of the used bottles (90%) are assumed to be collected for recycling into other systems where the material displaces 50% virgin raw materials and 50% recycled PET (see section 2.7.5). The remaining 10% end up in waste incineration where energy is recovered (see Tables 8.1 and 8.4).

8.2 Inventory analysis

8.2.1 50 cl disposable PET bottle

Input data

The bottle, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 8.1. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 6. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

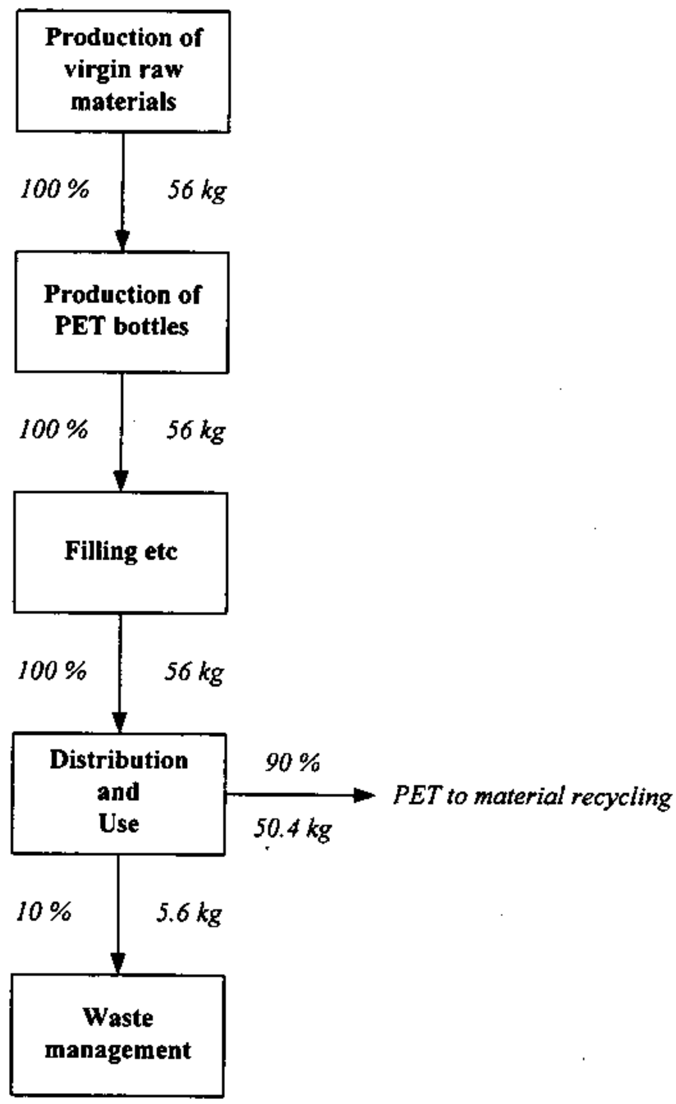

Figure 8.1
Flows of 50 cl disposable PET bottle system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure.

Table 8.1

System parameters for the packaging system with 50 cl disposable PET bottles. The mass presented refers to the weight of a single item, i.e., one bottle or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

	Name	Mass [g]	Market share	Material	Degree of reuse	Material to recycling	Material to disposal
Primary packaging	PET bottle (50 cl)	28	100 %	PET	0 %	90 %	10 %
Caps	Cap	2.0	100 %	PP	0 %	85 %	15 %
	Insert	0.2	100 %	LDPE	0 %	85 %	15 %
Labels	Label	0.6	100 %	Paper	0 %	0 %	100 %
	Glue	0.2	100 %	Casein/urea/H_2O	0 %	0 %	100 %
Secondary packaging	Box (24 bottles)	280	17 %	Corrugated board	0 %	20 %	80 %
	Tray (24 bottles)	200	50 %	Corrugated board	0 %	20 %	80 %
	Foil (24 bottles)	20	33 %	LDPE	0 %	0 %	100 %
	Multipack (6 bottles)	18	5 %	Cardboard	0 %	20 %	80 %
	Multipack (6 bottles)	15	5 %	LDPE	0 %	0 %	100 %
Transport packaging	Pallet (960 bottles)	22000	100 %	Wood	95 %	0 %	5 %
	Plastic ligature (960 bottles)	20	100 %	LDPE	0 %	70 %	30 %

Energy demand

An explanation of the disaggregation made in Table 8.2 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 8.2

Energy demand at final use for the packaging system with 50 cl disposable PET bottles. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	7.92E+01	-1.66E+01	6.26E+01
Electricity	*kWh*	*3.71*	*-2.03E+01*	*-1.66E+01*
Electricity, coal marginal	*kWh*	*7.55E+01*	*3.67*	*7.91E+01*
Fossil fuel, total	MJ	6.45E+03	-2.58E+03	3.87E+03
Coal	*MJ*	*1.05E+03*	*-4.17E+02*	*6.37E+02*
Coal, feedstock	*MJ*	*1.03E+03*	*-4.38E+02*	*5.88E+02*
Diesel, heavy & medium truck (highway)	*MJ*	*2.28E+02*	*-1.01E+02*	*1.27E+02*
Diesel, heavy & medium truck (rural)	*MJ*	*2.10E+03*	*-9.30E+02*	*1.17E+03*
Diesel, heavy & medium truck (urban)	*MJ*	*7.98E+02*	*-3.43E+02*	*4.55E+02*
Hard coal	*MJ*	*1.34E+02*	*2.64E+01*	*1.60E+02*
LPG, forklift	*MJ*	*7.61E+02*	*0*	*7.61E+02*
Natural gas (>100 kW)	*MJ*	*1.44E+02*	*-1.65E+02*	*-2.07E+01*
Natural gas	*MJ*	*8.96E+01*	*-5.96E-02*	*8.95E+01*
Natural gas, feedstock	*MJ*	*7.51E+01*	*4.77*	*7.99E+01*
Oil	*MJ*	*2.92E+01*	*1.04E+01*	*3.95E+01*
Oil, feedstock	*MJ*	*5.27*	*1.02E+01*	*1.54E+01*
Oil, heavy fuel	*MJ*	*3.64*	*-2.39E+02*	*-2.35E+02*
Renewable fuel, total	*MJ*	7.80	4.16	1.20E+01
Bark	*MJ*	*7.80*	*4.16*	*1.20E+01*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 8.3. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 6.

Table 8.3
Selection of inventory results for the packaging system with 50 cl disposable PET bottles. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags and ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Bauxite	g	1.93E+01	-8.59	1.07E+01
Brown coal	g	5.00E+02	-5.77E+01	4.42E+02
Coal	g	8.18E+03	-3.62E+03	4.56E+03
Coal, feedstock	g	2.18E+01	-9.67	1.21E+01
Crude oil	g	3.12E+04	-1.45E+04	1.66E+04
Crude oil, feedstock	g	4.91E+04	-2.18E+04	2.72E+04
Hard coal	g	4.32E+04	2.01E+03	4.52E+04
Hydro power-water	g	2.94E+09	-1.50E+09	1.44E+09
Iron ore	g	3.22E+01	-1.45E+01	1.77E+01
NaCl	g	3.04E+02	-1.33E+02	1.71E+02
Natural gas	g	2.15E+04	-1.17E+04	9.82E+03
Natural gas, feedstock	g	1.48E+04	-6.34E+03	8.45E+03
Softwood	g	1.20E+01	5.83E-01	1.26E+01
Surface water	g	1.31E+05	1.17E-06	1.31E+05
Water	g	1.06E+07	1.02E+06	1.16E+07
Non-elementary inflows				
Alum	g	1.24E+01	1.88E+01	3.12E+01
Auxiliary materials	g	1.20E+01	0	1.20E+01
Bark	g	4.58E+02	2.45E+02	7.03E+02
Binders	g	9.78E+01	0	9.78E+01
$Ca(OH)_2$	g	3.44E+02	2.12E+01	3.65E+02
$CaCO_3$	g	1.04E+01	1.57E+01	2.61E+01
CaO	g	2.78E+01	4.16E+01	6.94E+01
Corrugated board	g	3.78E+01	0	3.78E+01
Defoamer	g	5.40	5.58	1.10E+01
Dry strength additives	g	4.15E+01	0	4.15E+01
Fillers	g	4.42E+02	0	4.42E+02
H_2SO_4	g	9.90E+01	6.70E+01	1.66E+02
Ink	g	2.84E+01	0	2.84E+01
Lacquer, water	g	1.70E+01	0	1.70E+01
Na_2SO_4	g	1.64E+01	2.49E+01	4.13E+01

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	Unit	Packaging system	Effects on other product systems	Total
$NaClO_3$	g	5.65E+01	0	5.65E+01
Na_2CO_3	g	9.70	8.62	1.83E+01
NaOH	g	9.27E+01	3.70E+01	1.30E+02
NH_3	g	1.36E+01	0	1.36E+01
O_2	g	5.07E+01	0	5.07E+01
Other additives	g	1.77E+02	1.52	1.78E+02
Peat	g	3.20E+02	2.66E+01	3.46E+02
Pigment	g	3.72E+01	0	3.72E+01
Polymer filter screens	g	0	3.97E+01	3.97E+01
Retention agents	g	1.02E+01	8.62	1.88E+01
Sizing agents	g	3.50E+01	1.32E+01	4.82E+01
SO_2	g	4.10E+01	0	4.10E+01
Starch	g	2.77E+02	-1.25E+02	1.52E+02
Steel strappings	g	0	1.55E+02	1.55E+02
Sulphur	g	1.37E+01	1.02	1.47E+01
Emissions to air				
CH_4	g	3.63E+02	1.32E+02	4.96E+02
CO	g	1.28E+03	-4.49E+02	8.34E+02
CO_2	g	3.45E+05	-8.32E+04	2.62E+05
HC	g	2.40E+03	-1.03E+03	1.36E+03
HCl	g	2.64E+01	-2.67	2.38E+01
Hg	g	4.91E-03	9.04E-05	5.00E-03
NMVOC	g	6.30E+01	-4.07E+01	2.23E+01
NMVOC, diesel engines	g	3.30E+01	3.61	3.66E+01
NMVOC, electricity-coal	g	1.26	6.14E-02	1.32
NMVOC, oil combustion	g	6.78	2.36	9.14
NO_x	g	1.94E+03	-5.10E+02	1.43E+03
SO_2	g	2.55E+03	-6.62E+02	1.89E+03
Emissions to water				
Acid as H^+	g	1.05E+01	-4.72	5.78
BOD	g	5.65E+01	-2.54E+01	3.11E+01
BOD-5	g	2.82E+01	2.97E+01	5.79E+01
BOD-7	g	1.57E+01	0	1.57E+01
COD	g	2.79E+02	4.32	2.84E+02
Waste				
Bulk waste, total	g	3.14E+04	1.66E+04	4.80E+04
Elementary waste, corrugated board	*g*	*0*	*-6.18E+02*	*-6.18E+02*
Elementary waste, solid	*g*	*0*	*2.66E+04*	*2.66E+04*
Waste, bulky	*g*	*1.37E+04*	*6.65E+02*	*1.44E+04*
Waste, industrial	*g*	*8.95E+03*	*-9.47E+03*	*-5.21E+02*

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	Unit	Packaging system	Effects on other product systems	Total
Waste, inorganic sludges	*g*	*6.01E+01*	*7.96E+01*	*1.40E+02*
Waste, mineral	*g*	*6.92E+03*	*-7.85E+02*	*6.13E+03*
Waste, mixed industrial	*g*	*2.07E+02*	*-8.85E+01*	*1.18E+02*
Waste, other rejects	*g*	*2.81E+02*	*-9.08E+01*	*1.91E+02*
Waste, paper	*g*	*5.96E+02*	*0*	*5.96E+02*
Waste, paper production	*g*	*1.76E+02*	*0*	*1.76E+02*
Waste, PP	*g*	*1.84E+02*	*0*	*1.84E+02*
Glue to waste water treatment plant	*g*	*3.97E+01*	*4.01E+02*	*4.41E+02*
Hazardous waste, total	g	1.51E+03	-8.29E+02	6.83E+02
Waste, hazardous	*g*	*1.50E+03*	*-1.22E+03*	*2.78E+02*
Waste, polymer	*g*	*0*	*3.97E+02*	*3.97E+02*
Slags & ashes, total	g	2.98E+03	-1.81E+02	2.80E+03
Waste, ashes	*g*	*6.13E+02*	*-2.23E+02*	*3.91E+02*
Waste, slags & ashes (energy prod.)	*g*	*3.70E+02*	*1.80E+01*	*3.88E+02*
Waste, slags & ashes (waste incin.)	*g*	*2.04E-04*	*9.93E-06*	*2.14E-04*
Waste, slags & ashes	*g*	*2.00E+03*	*2.41E+01*	*2.02E+03*
Nuclear waste, total	g	1.19E+01	1.83	1.38E+01
Waste, highly radioactive	*g*	*1.19E+01*	*1.82*	*1.37E+01*
Waste, radioactive	*g*	*7.55E-02*	*4.89E-03*	*8.04E-02*
Co-products				
Biogas	g	0	-5.81E+01	-5.81E+01
Multipack-CB	g	5.99E+01	0	5.99E+01
Paper, fuel	g	1.96E+02	0	1.96E+02
Paper, recycling	g	1.00E+02	0	1.00E+02
Plastic ligature	g	2.18E+01	0	2.18E+01
Tall oil	g	5.32E+01	0	5.32E+01

Input data

8.2.2 150 cl disposable PET bottles

The bottle, the secondary packagings and transport packagings are quantitatively described by the system parameters in Table 8.4. Data and calculations on the environmental inputs and outputs of the processes in the process tree are presented in Technical report 6. Data on the environmental inputs and outputs of transports and on the production of fuels and electricity are presented in Technical report 7.

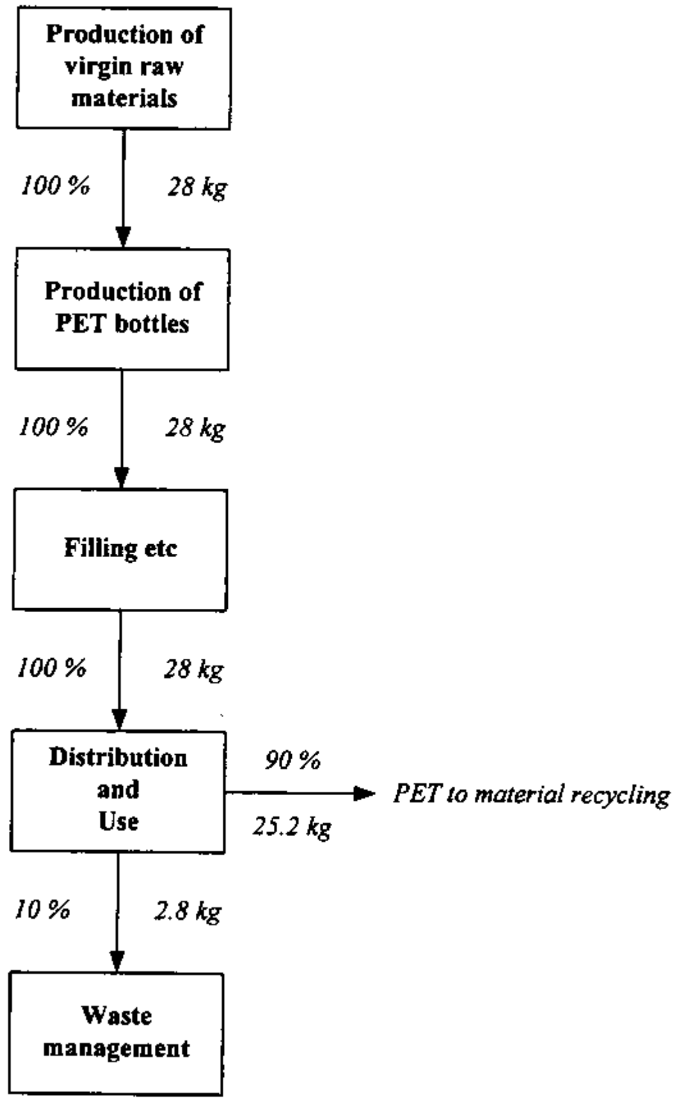

Figure 8.2

Flows of 150 cl disposable PET bottle system per 1000 litres of beverage. Flows of labels, caps, secondary packagings and transport packagings are not included in the figure.

Table 8.4

System parameters for the packaging system with 150 cl disposable PET bottles. The mass presented refers to the weight of a single item, i.e., one can or one tray. The market shares of the secondary packaging do not add up to 100% as they may be combined in different ways.

Name		Mass [g]	Market share	Material	Degree of reuse	Material to recycling	Material to disposal
Primary packaging	PET bottle (150 cl)	42	100 %	PET	0 %	90 %	10 %
Caps	Cap	2.0	100 %	PP	0 %	85 %	15 %
	Insert	0.2	100 %	LDPE	0 %	85 %	15 %
Labels	Label	0.8	100 %	Paper	0 %	0 %	100 %
	Glue	0.3	100 %	Casein/urea/H_2O	0 %	0 %	100 %
Secondary packaging	Box (10 bottles)	400	17 %	Corrugated board	0 %	20 %	80 %
	Tray (10 bottles)	100	50 %	Corrugated board	0 %	20 %	80 %
	Foil (10 bottles)	40	33 %	LDPE	0 %	0 %	100 %
	Multipack (3 bottles)	18	5 %	Cardboard	0 %	20 %	80 %
	Multipack (3 bottles)	15	5 %	LDPE	0 %	0 %	100 %
Transport packaging	Pallet (240 bottles)	22000	100 %	Wood	95 %	0 %	5 %
	Plastic ligature (240 bottles)	20	100 %	LDPE	0 %	70 %	30 %

Energy demand

An explanation of the disaggregation made in Table 8.5 is presented above Table 3.2.

Figure 2.1 indicates what unit processes are considered to be part of the packaging system and what processes are considered to be part of other systems.

Table 8.5

Energy demand at final use for the packaging system with 150 cl disposable PET bottles. These energy flows are not flows across the system boundary but internal flows within the system. Functional unit: packaging and distribution of 1000 litres. Energy carriers are excluded from the table if the total flow is less than 10 MJ/1000 litres.

	Unit	Packaging system	Effects on other product systems	Total
Electricity, total	kWh	5.05E+01	-7.84	4.27E+01
Electricity	*kWh*	*1.94*	*-8.95*	*-7.00*
Electricity, coal marginal	*kWh*	*4.86E+01*	*1.11*	*4.97E+01*
Fossil fuel, total	MJ	3.38E+03	-1.23E+03	2.15E+03
Coal	*MJ*	*1.15E+02*	*-4.51E+01*	*7.00E+01*
Diesel, heavy & medium truck (highway)	*MJ*	*1.08E+02*	*1.35E+01*	*1.21E+02*
Diesel, heavy & medium truck (rural)	*MJ*	*8.65E+01*	*-3.81E-02*	*8.64E+01*
Diesel, heavy & medium truck (urban)	*MJ*	*7.27E+01*	*2.86*	*7.55E+01*
Diesel, ship (4-stroke)	*MJ*	*3.46*	*6.50*	*9.97*
Hard coal	*MJ*	*3.81E+02*	*0*	*3.81E+02*
Natural gas (>100 kW)	*MJ*	*1.06E+02*	*-1.16E+02*	*-1.04E+01*
Natural gas	*MJ*	*5.15E+02*	*-1.95E+02*	*3.20E+02*
Natural gas, feedstock	*MJ*	*4.11E+02*	*-1.51E+02*	*2.60E+02*
Oil	*MJ*	*5.26E+02*	*-1.86E+02*	*3.40E+02*
Oil, feedstock	*MJ*	*1.04E+03*	*-4.07E+02*	*6.29E+02*
Oil, heavy fuel	*MJ*	*1.75E+01*	*6.62*	*2.41E+01*
Oil, light fuel	*MJ*	*2.73*	*-1.61E+02*	*-1.58E+02*
Renewable fuel, total	MJ	7.44	2.66	1.01E+01
Bark	*MJ*	*7.44*	*2.66*	*1.01E+01*

Inventory results

The resource demand, emissions and waste flows of the systems are presented in Table 8.6. An explanation is presented above Table 3.3

The table presents a selection of the inventory results only. For a complete list, see Technical report 6.

Table 8.6

Inventory results for the packaging system with 150 cl disposable PET bottles. Functional unit: packaging and distribution of 1000 litres. The table includes emissions that are significant for the characterisation. It also includes resource demand, non-elementary inflows, co-products and hazardous waste larger than 10 g/1000 litres. Bulk waste and slags & ashes are included if they amount to more than 100 g/1000 litres. All flows of radioactive waste are included in the table.

	Unit	Packaging system	Effects on other product systems	Total
Resources				
Brown coal	g	3.52E+02	-4.75E+01	3.04E+02
Coal	g	4.13E+03	-1.61E+03	2.52E+03
Crude oil	g	1.89E+04	-7.71E+03	1.11E+04
Crude oil, feedstock	g	2.43E+04	-9.54E+03	1.48E+04
Hard coal	g	2.79E+04	5.61E+02	2.85E+04
Hydro power-water	g	1.50E+09	-9.62E+08	5.42E+08
NaCl	g	1.54E+02	-5.87E+01	9.50E+01
Natural gas	g	1.17E+04	-6.14E+03	5.51E+03
Natural gas, feedstock	g	7.60E+03	-2.80E+03	4.80E+03
Surface water	g	5.77E+04	3.56E-07	5.77E+04
Water	g	6.59E+06	3.95E+05	6.98E+06
Non-elementary inflows				
Alum	g	7.96	1.20E+01	2.00E+01
Bark	g	4.38E+02	1.56E+02	5.94E+02
Binders	g	4.31E+01	0	4.31E+01
$Ca(OH)_2$	g	2.40E+02	8.45	2.48E+02
$CaCO_3$	g	6.67	1.01E+01	1.67E+01
CaO	g	1.78E+01	2.66E+01	4.45E+01
Corrugated board	g	1.67E+01	0	1.67E+01
Dry strength additives	g	1.83E+01	0	1.83E+01
Fillers	g	1.95E+02	0	1.95E+02
H_2SO_4	g	5.26E+01	4.28E+01	9.54E+01
HCl	g	1.12	-4.56E-01	6.65E-01
Ink	g	1.25E+01	0	1.25E+01
Na_2SO_4	g	1.05E+01	1.59E+01	2.64E+01
$NaClO_3$	g	2.49E+01	0	2.49E+01
Na_2CO_3	g	6.22	5.51	1.17E+01
NaOH	g	4.86E+01	2.37E+01	7.23E+01
O_2	g	2.24E+01	0	2.24E+01
Other additives	g	8.72E+01	9.73E-01	8.81E+01
Peat	g	1.93E+02	1.70E+01	2.10E+02

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	Unit	Packaging system	Effects on other product systems	Total
Pigment	g	1.24E+01	0	1.24E+01
Polymer filter screens	g	0	1.77E+01	1.77E+01
Retention agents	g	6.53	5.51	1.20E+01
Sizing agents	g	2.24E+01	8.43	3.09E+01
SO_2	g	1.84E+01	0	1.84E+01
Starch	g	1.77E+02	-8.01E+01	9.73E+01
Steel strappings	g	0	7.75E+01	7.75E+01
Emissions to air				
CH_4	g	2.42E+02	2.45E+01	2.66E+02
CO	g	7.02E+02	-2.02E+02	4.99E+02
CO_2	g	1.95E+05	-4.42E+04	1.51E+05
HC	g	1.20E+03	-4.62E+02	7.42E+02
HCl	g	1.40E+01	-1.23	1.27E+01
NMVOC	g	5.58E+01	-2.84E+01	2.74E+01
NMVOC, diesel engines	g	2.95E+01	1.97	3.14E+01
NMVOC, oil combustion	g	4.06	1.51	5.57
NO_x	g	1.10E+03	-2.30E+02	8.72E+02
SO_2	g	1.31E+03	-2.99E+02	1.01E+03
Emissions to water				
Acid as H^+	g	5.23	-2.10	3.13
BOD	g	2.84E+01	-1.14E+01	1.70E+01
BOD-5	g	1.81E+01	1.90E+01	3.71E+01
BOD-7	g	6.92	0	6.92
COD	g	1.54E+02	1.73E+01	1.71E+02
Waste				
Bulk waste, total	g	1.99E+04	4.56E+03	2.45E+04
Elementary waste, corrugated board	*g*	*0*	*-3.95E+02*	*-3.95E+02*
Elementary waste, solid	*g*	*0*	*1.17E+04*	*1.17E+04*
Waste, bulky	*g*	*8.84E+03*	*2.01E+02*	*9.04E+03*
Waste, mineral	*g*	*3.47E+03*	*-3.49E+02*	*3.12E+03*
Waste, other rejects	*g*	*1.80E+02*	*-5.81E+01*	*1.22E+02*
Waste, paper	*g*	*2.63E+02*	*0*	*2.63E+02*
Glue to waste water treatment plant	*g*	*2.01E+01*	*1.80E+02*	*2.00E+02*
Hazardous waste, total	g	1.07E+03	-6.98E+02	3.76E+02
Waste, hazardous	*g*	*1.07E+03*	*-8.73E+02*	*1.95E+02*
Waste, polymer	*g*	*0*	*1.77E+02*	*1.77E+02*
Slags & ashes, total	g	1.66E+03	-7.81E+01	1.58E+03
Waste, ashes	*g*	*3.15E+02*	*-9.32E+01*	*2.22E+02*

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	Unit	Packaging system	Effects on other product systems	Total
Waste, slags & ashes (energy prod.)	*g*	*2.38E+02*	*5.42*	*2.43E+02*
Waste, slags & ashes	*g*	*1.11E+03*	*9.60*	*1.12E+03*
Nuclear waste, total	g	9.54	9.64E-01	1.05E+01
Waste, highly radioactive	*g*	*9.50*	*9.62E-01*	*1.05E+01*
Waste, radioactive	*g*	*4.84E-02*	*1.95E-03*	*5.04E-02*
Co-products				
Biogas	g	0	-3.71E+01	-3.71E+01
Multipack-CB	g	4.00E+01	0	4.00E+01
Paper, fuel	g	8.64E+01	0	8.64E+01
Paper, recycling	g	4.41E+01	0	4.41E+01
Plastic ligature	g	2.92E+01	0	2.92E+01
Tall oil	g	2.35E+01	0	2.35E+01

8.3 Impact assessment

This section presents results from the impact assessment of packaging systems with disposable PET bottles. The most important characterisation calculations and results are presented in Tables 8.7 and 8.8. For a full presentation of the classification and characterisation, we refer to Technical report 6

Normalisation results are presented in Tables 8.9 and 8.10. Weighting results are presented in Tables 8.11 and 8.12.

Table 8.7

Classification and characterisation of the packaging system with 50 cl disposable PET bottles. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient enrichment potential (NP) [kg NO_3^--equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NO_x	1.35 E-03	2.62	-6.89E-01	1.93
Total		**2.64**	**-6.97E-01**	**1.95**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Characterisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	2.54E-03	9.26E-04	3.47E-03
CO	3.00E-05	3.85E-02	-1.35E-02	2.50E-02
HC	6.00E-04	1.44	-6.20E-01	8.17E-01
NMVOC	4.00E-04	2.52E-02	-1.63E-02	8.93E-03
NMVOC, diesel engines	6.00E-04	1.98E-02	2.16E-03	2.20E-02
NMVOC, electricity-coal	8.00E-04	1.01E-03	4.91E-05	1.06E-03
NMVOC, oil combustion	3.00E-04	2.03E-03	7.08E-04	2.74E-03
Total		**1.53**	**-6.47E-01**	**8.80E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	2.33E-02	-2.35E-03	2.09E-02
NO_x	7.00E-04	1.36	-3.57E-01	1.00
SO_2	1.00E-03	2.55	-6.62E-01	1.89
Emissions to water				
Acid as H^+	3.20E-02	3.36E-01	-1.51E-01	1.85E-01
Total		**4.27**	**-1.17**	**3.10**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	9.08	3.31	1.24E+01
CO	2.00E-03	2.57	-8.98E-01	1.67
CO_2	1.00E-03	3.45E+02	-8.32E+01	2.62E+02
HC	3.00E-03	7.19	-3.10	4.08
Total		**3.64E+02**	**-8.39E+01**	**2.80E+02**

Table 8.8

Classification and characterisation of the packaging system with 150 cl disposable PET bottles. The unit of the characterisation factor is g equivalent per g emission. The table includes only parameters that contribute significantly to the environmental impacts. Functional unit: packaging and distribution of 1000 litres.

Nutrient potential (NP) [kg NO_3^--equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
NO_x	1.35 E-03	1.49	-3.11E-01	1.18
Total		**1.50**	**-3.16E-01**	**1.18**

Photochemical ozone creation potential (POCP) [kg C_2H_4-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	7.00E-06	1.69E-03	1.72E-04	1.86E-03
CO	3.00E-05	2.10E-02	-6.07E-03	1.50E-02
HC	6.00E-04	7.22E-01	-2.77E-01	4.45E-01
NMVOC	4.00E-04	2.23E-02	-1.14E-02	1.10E-02
NMVOC, diesel engines	6.00E-04	1.77E-02	1.18E-03	1.89E-02
NMVOC, oil combustion	3.00E-04	1.22E-03	4.52E-04	1.67E-03
Total		**7.87E-01**	**-2.93E-01**	**4.94E-01**

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Acidification potential (AP) [kg SO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
HCl	8.80E-04	1.23E-02	-1.08E-03	1.12E-02
NO_x	7.00E-04	7.72E-01	-1.61E-01	6.10E-01
SO_2	1.00E-03	1.31	-2.99E-01	1.01
Emissions to water				
Acid as H^+	3.20E-02	1.67E-01	-6.71E-02	1.00E-01
Total		**2.26**	**-5.28E-01**	**1.73**

Global warming potential (GWP) [kg CO_2-equivalents]	Charact-erisation factor	Packaging system	Effects on other product systems	Total
Emissions to air				
CH_4	2.50E-02	6.04	6.13E-01	6.66
CO_2	1.00E-03	1.95E+02	-4.42E+01	1.51E+02
HC	3.00E-03	3.61	-1.38	2.23
Total		**2.07E+02**	**-4.53E+01**	**1.61E+02**

Table 8.9

Normalisation results for the packaging system with 50 cl disposable PET bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system $[PE_{WDK90}]$ (2)	Effects on other product systems $[PE_{WDK90}]$ (2)	Total $[PE_{WDK90}]$ (2)
Environmental impacts				
Global warming (GWP)	8700	4.19E-02	-9.65E-03	3.22E-02
Photochemical ozone formation (POCP)	20	7.64E-02	-3.23E-02	4.40E-02
Acidification (AP)	124	3.45E-02	-9.45E-03	2.50E-02
Nutrient enrichment (NP)	298	8.87E-03	-2.34E-03	6.53E-03
Waste				
Bulk waste (non-hazardous)	1350	2.32E-02	1.20E-02	3.52E-02
Hazardous waste	20.7	7.30E-02	-4.00E-02	3.30E-02
Slag and ashes	320	8.51E-03	-5.16E-04	8.00E-03
Nuclear waste	0.159	7.51E-02	1.15E-02	8.66E-02
Resources				
Oil	590	1.36E-01	-6.17E-02	7.43E-02
Coal	570	5.52E-02	-1.75E-03	5.34E-02
Brown coal	250	2.00E-03	-2.31E-04	1.77E-03
Natural gas	310	1.17E-01	-5.82E-02	5.89E-02

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 8.10

Normalisation results for the packaging system with 150 cl disposable PET bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 1 mPE/1000 litres are not included in the table.

Normalisation: Environmental impact categories	Normalisation reference (1)	Packaging system [PE_{WDK90}] (2)	Effects on other product systems [PE_{WDK90}] (2)	Total [PE_{WDK90}] (2)
Environmental impacts				
Global warming (GWP)	8700	2.38E-02	-5.21E-03	1.85E-02
Photochemical ozone formation (POCP)	20	3.94E-02	-1.46E-02	2.47E-02
Acidification (AP)	124	1.82E-02	-4.26E-03	1.40E-02
Nutrient enrichment (NP)	298	5.04E-03	-1.06E-03	3.98E-03
Waste				
Bulk waste (non-hazardous)	1350	1.47E-02	3.24E-03	1.80E-02
Hazardous waste	20.7	5.19E-02	-3.37E-02	1.82E-02
Slag and ashes	320	4.74E-03	-2.23E-04	4.52E-03
Nuclear waste	0.159	6.00E-02	6.06E-03	6.61E-02
Resources				
Oil	590	7.32E-02	-2.92E-02	4.39E-02
Coal	570	3.44E-02	-1.13E-03	3.33E-02
Brown coal	250	1.41E-03	-1.90E-04	1.22E-03
Natural gas	310	6.21E-02	-2.88E-02	3.33E-02

(1) The normalisation references have the following units: characterisation equivalent/pers/year (for environmental impacts), kg/pers/year (for waste) m^3/pers/year (for wood) and kg/pers/year (for other resources).

(2) PE_{WDK90}: person equivalent based on emission levels, waste levels and resource demand in the year 1990.

Table 8.11

Weighting results for the packaging system with 50 cl disposable PET bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	[$PET_{WDK2000}$ /PE_{WDK90}] (1)	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Global warming (GWP)	1.3	5.44E-02	-1.25E-02	4.19E-02
Photochemical ozone formation (POCP)	1.2	9.16E-02	-3.88E-02	5.28E-02
Acidification (AP)	1.3	4.48E-02	-1.23E-02	3.25E-02
Nutrient enrichment (NP)	1.2	1.06E-02	-2.81E-03	7.83E-03
Waste	[$PET_{WDK2000}$/PE_{WDK90}]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]	[$PET_{WDK2000}$]
Bulk waste (non-hazardous)	1.1	2.55E-02	1.32E-02	3.88E-02
Hazardous waste	1.1	8.03E-02	-4.40E-02	3.63E-02
Slag and ashes	1.1	9.36E-03	-5.68E-04	8.80E-03
Nuclear waste	1.1	8.26E-02	1.27E-02	9.53E-02
Resources	[PR_{W90}/PE_{WDK90}]	[PR_{W90}] (2)	[PR_{W90}]	[PR_{W90}]
Oil	2.30E-02	3.13E-03	-1.42E-03	1.71E-03
Coal	5.80E-03	3.20E-04	-1.01E-05	3.10E-04
Natural gas	1.60E-02	1.87E-03	-9.31E-04	9.43E-04

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

Table 8.12

Weighting results for the packaging system with 150 cl disposable PET bottles. Functional unit: packaging and distribution of 1000 litres. Resource depletions below 0.01 mPR/1000 litres are not included in the table.

Weighting: Environmental impact categories	Weighting factor	Packaging system	Effects on other product systems	Total
Environmental impacts	$[PET_{WDK2000}/PE_{WDK90}]$ (1)	$[PET_{WDK2000}]$	$[PET_{WDK2000}]$	$[PET_{WDK2000}]$
Global warming (GWP)	1.3	3.09E-02	-6.78E-03	2.41E-02
Photochemical ozone formation (POCP)	1.2	4.72E-02	-1.76E-02	2.97E-02
Acidification (AP)	1.3	2.37E-02	-5.53E-03	1.82E-02
Nutrient enrichment (NP)	1.2	6.04E-03	-1.27E-03	4.77E-03
Waste	$[PET_{WDK2000}/PE_{WDK90}]$	$[PET_{WDK2000}]$	$[PET_{WDK2000}]$	$[PET_{WDK2000}]$
Bulk waste (non-hazardous)	1.1	1.62E-02	3.56E-03	1.98E-02
Hazardous waste	1.1	5.71E-02	-3.71E-02	2.00E-02
Slag and ashes	1.1	5.22E-03	-2.46E-04	4.97E-03
Nuclear waste	1.1	6.60E-02	6.67E-03	7.27E-02
Resources	$[PR_{W90}/PE_{WDK90}]$	$[PR_{W90}]$ (2)	$[PR_{W90}]$	$[PR_{W90}]$
Oil	2.30E-02	1.68E-03	-6.73E-04	1.01E-03
Coal	5.80E-03	1.99E-04	-6.56E-06	1.93E-04
Natural gas	1.60E-02	9.94E-04	-4.61E-04	5.32E-04

(1) $PET_{WDK2000}$: person equivalent based on target emissions in the year 2000.
PE_{WDK90}: person equivalent based on emission levels in the year 1990.

(2) PR_{W90}: person-reserve, *i.e.*, the fraction of known global reserves per person, in 1990.

8.4 Interpretation

Important impacts

The packaging systems with disposable PET bottles contribute most to the following non-toxicological environmental impacts (see Tables 8.9-8.12):

- photochemical ozone formation (POCP), and
- global warming (GWP)

Waste and resources

The disposable PET bottle systems contribute less than 100 mPET for all waste categories. They contribute significantly (>1 mPR) to the depletion of oil resources.

Important processes

The most important processes for the environmental impacts of the 50 cl disposable PET bottle system are presented in Table 8.13.

Table 8.13
The most important processes of the 50 cl disposable PET bottle system. The figures are given in % of the net total potential environmental impact.

	GWP	POCP	AP	NP
1. PET-resin production	54	156	82	79
3. Bottle production	45		41	27
Trp 19. Distribution of beverage				13
44. PET-production (avoided)	-22	-70	-36	-35
61. Alternative energy production	-11			

PET-resin production

The largest contributions to POCP, AP, NP and GWP are caused by hydro carbon emissions (POCP), emissions of SO_2 and NO_x (AP), NO_x (NP) and emissions of CO_2 (GWP) from the PET-resin production.

Bottle production

The bottle production contributes to GWP, AP and NP mainly due to the emissions of CO_2 (GWP), SO_2 (AP) and NO_x (NP).

Distribution of beverage

The distribution of beverage contributes to NP due to emissions of NO_x.

PET-production (avoided)

The avoided PET-production mainly contributes to avoided impacts for POCP, AP, NP and GWP due to avoided emissions of hydro carbons (POCP), SO_2 (AP), NO_x (NP) and CO_2 (GWP).

Alternative energy prod.

The alternative energy production in the waste incineration contributes to avoided impacts for GWP due to avoided emissions of CO_2.

Resource demand

The oil is mainly used in the production of PET-resin. Half of it is crude oil used for fuels. The other half is crude oil used as feedstock.

Sensitivity analyses

Sensitivity analyses were carried through as described in section 2.13. The quantitative results are presented in Table 8.14.

Table 8.14
Results from the quantitative sensitivity analyses made on the packaging system with 50 cl disposable PET bottles. Functional unit: packaging and distribution of 1000 litres.

Parameters	Base case [g/1000 l beverage]	Bottle weight (+ 20 %) [% of basics]	100 % virgin PET & PP in recycling [% of base case]	Distribution (light truck) [% of base case]	Electricity, fragmented markets [% of base case]	Electricity, European base load average [% of base case]
CO_2	2,55E+05	119	80	107	101	91
SO_2	1,89E+03	118	66	101	99	111
NO_x	1,42E+03	116	65	109	100	96
VOC, total	1,90E+03	119	35	104	99	90

Bottle weight

The bottle weight is 28 g in the base case. This could be compared to 25 g in the previous study. A sensitivity scenario corresponding to an increase of the bottle weight by 20 % (34 g) was performed. The results for some of the important inventory parameters are shown in Table 8.14. The bottle weight appears to be of minor importance especially since the bottle weight increase of 20 % is excessive.

Allocation methods

In the recycling of discarded PET bottles and PP caps it is assumed that 50 % of the PET and PP replaces virgin raw materials and that 50 % replaces recycled material from other products. A sensitivity scenario was calculated, in which the recycled PET bottles and PP caps were assumed to replace 100 % virgin material. The results indicate that this assumption is important for the LCA results. The most important difference between the sensitivity scenario and the base case scenario is that avoided PET production is doubled. This is particularly important for POCP, AP, NP and GWP as indicated by the dominance analysis above (see Table 8.13).

Use of recycled PET

If recycled PET is used in the production of PET bottles, the increased demand for recycled PET would affect other systems. The effect on other systems depends on what is the alternative fate of the recycled material: waste disposal or recycling into other products (see Main report, section 2.6.2). To be consistent with the base case assumption that recycled PET from the packaging systems replaces 50% virgin raw materials and 50% recycled materials from other systems, we here assume that the alternative fate of the recycled PET is 50% waste disposal and 50% recycling into other products.

The use of 1 ton recycled material in PET bottles would reduce the primary PET production in the packaging system by nearly 1 ton. However, under the 50/50 assumption discussed above, the primary PET production in other systems would be increased by approximately 0.5 ton. The net effect is that primary production is reduced by approximately 0.5 ton. As indicated by the dominance analysis, this would have a significant effect on the POCP, AP, NP and GWP results.

Distribution of beverage

A sensitivity analysis regarding the distribution of beverage was performed. Using data for light truck does not affect the results (Table 8.14).

Electricity production

The electricity data used in the base case are coal marginal. Two sensitivity analyses were performed for electricity production (long term base load at fragmented markets and European base load average). It is clear from the results (Table 8.14) that the assumption regarding the electricity production is of minor importance.

Data gaps and omissions

The most important data gaps are:

- Lack of information concerning the process efficiencies in the production of preforms/bottles i.e. the amount of material waste is unknown.
- No information about potential water emissions in the washing and filling process.

The analysis did not include the production of a large number of ancillary materials. The most important non-elementary inflows are bark (corrugated board, cardboard, paper and planks), fillers (paper), calcium hydroxide (waste incineration) and peat (corrugated board, cardboard and paper).

Production of materials for secondary packagings (multipacks), transport packaging (pallets and plastic ligature) and cap inserts is included in the LCA, but the actual packaging production - conversion, nailing etc. - is not included.

Neither did the analysis include the environmental impacts of the retailer, nor the private transport home from the retailer. These omissions affect the total energy demand of the system by approximately 1% each.

There are important data gaps in the characterisation of POCP, human toxicity in air and soil, and chronic terrestrial and aquatic ecotoxicity.

Uncertainties

The data quality for the most important processes (production of PET-resin and bottles, distribution of beverage and avoided PET-production) is assessed to have medium to small uncertainty, good completeness and good to fair representativity.

The uncertainties in the normalisation of toxicity impacts are large. However, this does not affect the comparisons between the systems.

For further details, see Technical report 6.

9 Comparability of the systems

Comparisons

Different versions of six different packaging systems are covered by this LCA (see Table 2.1). We only compare packagings of the same volume. As indicated above (section 2.4), comparisons between containers of different sizes are difficult, because the size of the packaging is likely to affect the beverage consumption. Furthermore, containers with different sizes fulfil partly different functions.

Based on the volume of the packaging, five different comparisons between packaging systems are possible:

- between the four different 33cl packaging systems for beer,
- between 50cl steel and aluminium cans for beer,
- between three different 33cl packaging systems for soft drinks (with an additional extrapolation from 25cl refillable glass bottles),
- between the four different 50cl packaging systems for soft drinks, and
- between refillable and disposable 150cl PET bottles

Container size

The fact that only packagings with the same size are compared is likely to be disadvantageous for the refillable glass bottles. On a real market, the 33 cl glass bottles for beer would compete not only with 33 cl cans but also with 50 cl cans. The use of 50 cl cans would probably result in a higher beer consumption. This means the environmental impacts from beer production would be increased. This potentially important increase is not taken into account in this study.

The 25 cl refillable glass bottle for soft drinks competes with larger containers. The use of larger containers would probably result in increased production of soft drinks, and in increased environmental impacts from these processes.

Functional unit / function

The same functional unit is used in the studies of each individual system: the packaging and distribution of 1000 litres of beverage. In the comparisons, the functional unit is based on the average annual consumption of the relevant beverage for one person in Denmark in 1993 - rather than 1000 litres - *i.e.*, 128.2 litres of beer and 72.3 litres of carbonated soft drinks. The same amounts were used in the previous study. This change in scale does not affect the conclusions made in this study regarding the comparison of systems.

The functional unit reflects the main functions of the system: packaging and distribution of the beverages. However, it should be noted that from a consumer perspective, the performance of the packagings differs slightly, *e.g.*, due to the differences in packaging weight and shape.

Inventory method

The same criteria have been used for deciding what materials should be cut-off and for defining other system boundaries. Systems were expanded to include effects of other systems, *e.g.*, of the recycling of materials from the packaging systems. The criterion for this system expansion was that the flow of recycled material should be at least 1% of the primary packaging weight. This criteria is slightly disadvantageous for the glass bottles. It can be assumed that half of the steel in glass bottle caps is recovered from the ashes after waste incineration, but this recycling was not included in the assessment, since the flow is small. This cut off means that the iron resource demand of the glass bottle systems is nearly doubled. For other impacts, the effect is very small.

The same considerations have been used as a basis for the allocation procedure in all systems. A closed-loop approach was used in the aluminium can systems, but this does not affect the results. Different assumptions were made on the effects of recycling of different materials, but these assumptions were all based on an analysis of the long-term effects on the markets for recycled material (see section 2.7.5).

Consumer behaviour

We assume consumer behaviour to be largely independent of the packaging system (see section 2.7.1). The consumption of beer and carbonated soft drinks is assumed not to be significantly affected by the choice between packagings of the same size. This assumption may favour the lighter packagings - the aluminium and steel cans - because the consumers may buy more beer and soft drinks if they are easier to carry.

The decision to use a drinking glass is assumed not to be affected by the packaging. This assumption may also favour the aluminium and steel cans, because the consumers may be less prone to drink directly from a can than from a bottle. If so, then the can systems would require more washing of drinking glasses.

On the other hand, the mode of private transportation is also assumed to be unaffected. This assumption can favour the glass bottles, because the comsumer may in fact decide to use the car more often when buying beer and soft drinks in the heavier glass bottles.

Data quality

The same requirements on data quality apply to all systems. Based on the goal definition, we decided that the most relevant data for this study reflect long-term marginal technology. This decision is most important for the data on electricity production. Compared to using, *e.g.*, national average data on electricity production, the electricity data used in the base case scenario are likely to favour the bottles. For this reason it is important to note that our conclusions are based not only on the base case results. The uncertainties regarding the marginal electricity production and its environmental impacts are large, and our conclusions take the full uncertainties into account.

The quality of the actual data obtained varies. Site specific data were collected for glass production, but average data were used for primary production of primary aluminium, steel and PET. This is due to the fact that it is fairly certain at which site the glass will be produced, but it is uncertain where the other materials will be produced. For all of these materials, the data are recent or fairly recent.

Impacts considered

The comparisons are based on the energy demand and impact assessment results for the different packaging systems. The comparison includes most of the impact categories presented in Table 2.4. Stratospheric ozone depletion is excluded from the comparison since no emissions contributing significantly to this category were reported. This is consistent with the results from the previous study (Wesnæs 1996).

Nuclear waste is associated with nuclear power production. However, nuclear power should not be included in the base case electricity scenario, on which the quantitative comparisons are based. However, the base case calculations do include a small share of nuclear power. This is because the data collected for production of plastics and fuel were aggregated and included (average) electricity power production. We recalculated the data for PET production, since the PET data are important for the PET bottle systems. It was not feasible within this project to disaggregate the data for production of fuel and plastics used in smaller amounts. The consequence is that the radioactive waste recorded in the LCA results does not reflect any true difference between the packaging systems. For this reason the nuclear waste is also excluded from the comparison. Nuclear waste was included in the comparisons made in the previous study. This is consistent with the fact that average electricity was used (see section 2.7.3).

A large number of different resources are used in the packaging systems (see Technical reports 1-6). The EDIP impact assessment method does not take all of these into account, but we belive that the comparisons include the most significant depletion of non-renewable resources: different fossil fuels, aluminium, iron, manganese and tin. Compared to the previous study, this means that manganese depletion has been added to the comparison (Wesnæs 1996).

Impact assessment

The same impact assessment method has been used for all systems. The choice of weighting factors is not objective, and there is no international consensus on the choice of normalisation reference. However, the normalisation references and the weighting factors do not affect the conclusions made in this study regarding the comparison of systems. The comparisons are made separately for each environmental impact category. Within each category, the normalisation reference and the weighting factor are only scale factors that affect all systems equally.

10 Comparison of 33 cl beer packagings

10.1 Introduction

Systems compared

The LCAs summarised above include the assessment of systems with four different 33 cl packagings for beer:

- refillable, green glass bottles,
- disposable, green glass bottles,
- aluminium cans, and
- steel cans.

Limitations

This chapter presents an environmental comparison of the four packaging systems. The comparison is limited to the environmental impacts covered by the LCAs. This means that, *e.g.*, work environment and health impacts from use and misuse of the packaging are not included in the comparison.

10.2 Comparing base case scenarios

Energy at final use

The total amounts of fuel and electricity used in the processes and transports are compared in Table 10.1. It should be noted that the table presents the final use of fuel and electricity, not the demand for primary energy. This means that, *e.g.*, the fossil fuel demand does not include fossil fuel used for electricity production.

In the base case, the total energy demand at final use is lower for the refillable glass bottle and the aluminium can than for the competing systems.

Electricity demand

The electricity demand is high for the aluminium and steel cans. Approximately half of this electricity is used in the production of primary aluminium - for the aluminium can and for the aluminium lid on the steel can - and in can production.

Fossil fuel demand

The demand for fossil fuel at final use is low for the aluminium can. It is high in the disposable glass bottle system. The main reason is the fuel demand at production of glass and raw materials (see the dominance analysis in Technical report 2).

Other energy carriers

The demand for renewable fuel and other energy carriers is small in all systems. Two systems even produce a small net surplus of steam and/or other energy carriers.

Table 10.1

Net total energy demand at final use for 33 cl beer packaging systems in the base case. Functional unit: packaging and distribution of 128.2 litres of beer.

Energy demand	Unit	Refillable glass bottle	Disposable glass bottle	Aluminium can	Steel can
Electricity	kWh	1.05E+01	2.13E+01	3.85E+01	3.91E+01
Fossil fuel	MJ	1.68E+02	3.72E+02	1.27E+02	2.20E+02
Renewable fuel	MJ	9.69E-01	2.56E+00	1.93E+00	1.86E+00
Heat etc.	MJ	5.67E-01	-8.48E+00	-1.12E+00	1.59E+01

Primary energy

The demand for primary fossil energy resources is presented in Tables 10.2-3. The demand for oil and coal is lower for the refillable bottle than for the competing packagings.

Table 10.2

Normalisation of net total depletion of selected resources for 33 cl beer packaging systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 128.2 litres of beer. The unit of the normalisation reference is kg per person and year.

Resource	Normalisation Reference	Refillable glass bottle [PE/FU]	Disposable glass bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Oil	590	2.4E-03	4.0E-03	4.8E-03	6.3E-03
Coal	931	7.5E-03	1.4E-02	2.4E-02	3.8E-02
Brown coal	250	3.0E-04	5.7E-04	8.3E-04	1.3E-03
Natural gas	310	5.9E-03	9.5E-04	5.0E-03	9.5E-03
Aluminium	3.4	2.5E-03	6.0E-04	2.4E-01	3.3E-01
Iron	100	7.0E-03	7.0E-03	2.9E-07	7.0E-03
Manganese	1.8	3.2E-08	5.2E-08	6.7E-03	1.4E-07
Tin	0.04	4.3E-02	4.2E-02	0	6.4E-01

Table 10.3

Selected weighting results for net total resource depletion of 33 cl beer packaging systems in the base case. The unit is person-reserve (PR) per functional unit (FU). The person-reserve is the fraction of the known global reserves per person in the world in 1990 (Hauschild & Wenzel 1998). The functional unit is the packaging and distribution of 128.2 litres of beer.

Resource	Weighting factors	Refillable glass bottle [PR/FU]	Disposable glass bottle [PR/FU]	Aluminium can [PR/FU]	Steel can [PR/FU]
Oil	0.023	6.5E-05	9.3E-05	1.1E-04	1.4E-04
Coal	0.0058	5.4E-05	8.2E-05	1.3E-04	2.1E-04
Brown coal	0.0026	8.9E-07	1.5E-06	2.0E-06	3.3E-06
Natural gas	0.016	1.1E-04	1.5E-05	8.0E-05	1.5E-04
Aluminium	0.0051	1.3E-05	3.0E-06	1.2E-03	1.7E-03
Iron	0.0085	6.0E-05	5.9E-05	2.5E-09	5.9E-05
Manganese	0.012	3.8E-10	6.3E-10	8.1E-05	1.6E-09
Tin	0.037	1.6E-03	1.6E-03	0	2.4E-02

Although the demand for fossil fuel at final use is low for the aluminium can, the demand for primary fossil energy is relatively high. The reason is that the electricity production is based on coal in the base case scenario.

The steel can has the highest demand for all fossil fuels. Most of the coal is used for production of electricity which is used in, *e.g.*, the production of primary aluminium and tinsteel cans. A significant share of the coal is also used as coke for pig iron production.

The refillable glass bottle demands a relatively large amount of natural gas. Most of this is used for the washing and filling processes at the brewery.

Metals demand

Regarding the demand for metal resources, the comparison shows some rather interesting results. The demand for aluminium is higher in the steel can systems than in the aluminium can system. The same relation was valid in the previous study. The reason for this relation is that 90% of the aluminium cans are assumed to be collected and remelted to produce secondary aluminium which replaces primary aluminium. The aluminium lid on the steel can is oxidised in the steel recycling process. The energy in the aluminium lid is utilised, but the material is lost.

The demand for iron is as large in the glass bottle systems as in the steel can system. This is partly due to our criteria for defining system boundaries. The reason is that 90% of the steel cans are assumed to be collected for recycling. The remaining 10% go to waste incineration, but half of this steel is recovered from the ashes and recycled, replacing primary steel. This means that 95% of the steel is recovered for recycling.

Each distributed glass bottle holds a cap. Most of the caps are produced from tinsteel. The caps end up at waste incineration. It can be assumed that half of the steel is recovered from the ashes and recycled, but this flow is so small (less than 1% of primary packaging weight) that the systems boundaries were not expanded to include this recycling.

Manganese is used as an alloy in the aluminium can.

Tin is used for producing tinsteel. The tin demand is higher for the steel can than for the glass bottles, since the tin is not recovered at steel can recycling.

Global warming

In the base case scenario, the global warming potential (GWP) of the refillable glass bottle is less than half the GWP of the competing systems (see Tables 10.4-6). The GWP is mainly associated with CO_2 emissions. In the steel can and aluminium can systems, more than half of the CO_2 is emitted at production of electricity which is used, *e.g.*, at the production of primary aluminium and cans. In addition, significant amounts of CO_2 are emitted through combustion of fossil fuel in processes associated to primary production of steel and aluminium (see also dominance analyses in Technical reports 3-4).

In the disposable glass bottle system, the CO_2 emissions are mainly caused by glass production.

Table 10.4

Comparison of net total potential environmental impacts for 33 cl beer packaging systems in the base case. The table presents characterisation results for non-toxicological impacts. Functional unit: packaging and distribution of 128.2 litres of beer.

Environmental impacts	Unit	Refillable glass bottle	Disposable glass bottle	Aluminium can	Steel can
Global warming	kg CO_2-eq	2.2E+01	4.6E+01	4.7E+01	5.8E+01
Photochemical ozone formation	kg C_2H_4-eq	1.2E-02	1.9E-02	1.7E-02	2.2E-02
Acidification	kg SO_2-eq	9.6E-02	2.9E-01	2.2E-01	2.7E-01
Nutrient enrichment	kg NO_3-eq	1.2E-01	3.2E-01	2.2E-01	2.7E-01

Table 10.5
Normalisation of net total potential environmental impacts for 33 cl beer packaging systems in the base case. The unit of the normalised impacts is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 128.2 litres of beer.

Environmental impacts	Normalisation reference	Refillable glass bottle [PE/FU]	Disposable glass bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Global warming	8700	2.6E-03	5.3E-03	5.4E-03	6.7E-03
Photochemical ozone formation	20	6.0E-04	9.4E-04	8.6E-04	1.1E-03
Acidification	124	7.7E-04	2.3E-03	1.8E-03	2.2E-03
Nutrient enrichment	298	4.0E-04	1.1E-03	7.3E-04	9.0E-04

Table 10.6
Weighting of net total potential environmental impacts for 33 cl beer packaging systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refers to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 128.2 litres of beer.

Environmental impacts	Weighting factor	Refillable glass bottle [PET/FU]	Disposable glass bottle [PET/FU]	Aluminium can [PET/FU]	Steel can [PET/FU]
Global warming	1.2	3.3E-03	6.8E-03	7.1E-03	8.7E-03
Photochemical ozone formation	1.2	7.3E-04	1.1E-03	1.0E-03	1.3E-03
Acidification	1.3	1.0E-03	3.0E-03	2.3E-03	2.9E-03
Nutrient enrichment	1.3	4.7E-04	1.3E-03	8.8E-04	1.1E-03

POCP

The potential photochemical formation of ozone (POCP) is nearly twice as high for the steel can compared to the refillable glass bottle in the base case. The POCP of the aluminium can and the disposable glass bottle is somewhere in between.

In the refillable glass bottle system, the distribution of the beverage is responsible for more than half of the net total POCP in the base case (see section 3.4). The distribution is not quite so important for the other systems, partly because the net total POCP is larger for these systems. Furthermore, the emissions from the distribution are smaller for the steel and aluminium can systems, because these packagings are lighter.

For the disposable glass bottle system, the distribution, the production of raw materials, and the glass production contributes the most to the POCP. For aluminium cans, the distribution, primary aluminium production and can production are important (see section 5.4). In the steel can system, most of the POCP is caused by emissions associated with tinplate and can production (section 6.4).

Acidification

In the base case, the disposable glass bottle and the steel can contribute approximately three times as much to the potential acidification compared to the refillable glass bottle. The acidification potential of the aluminium can system is more than twice the potential of the refillable bottle.

The production of aluminium, steel and cans is important for the acidification potential of the can systems. Glass production is important for the disposable glass bottle system.

Nutrification

The results indicate that the nutrification potential of the disposable glass bottle and the steel can is more than double the potential for the refillable bottle. The nutrification potential of the aluminium can is slightly less than twice the potential of the refillable bottle, in the base case scenario. The difference between the systems is to a large extent caused by emissions associated with the production of glass, aluminium, steel, and cans.

Waste

The can systems generate more bulk waste than the glass bottle systems in the base case scenario (see Tables 10.7-8). The disposable glass bottle generates less hazardous waste than the competing packagings. The steel can generates more than the other packagings. For slags & ashes, the relations are the opposite.

Table 10.7

Normalisation of waste flows from 33 cl beer packaging systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 128.2 litres of beer. The unit of the normalisation reference is kg per person and year.

Waste category	Normalisation Reference	Refillable glass bottle [PE/FU]	Disposable glass bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Bulk waste	1350	5.7E-03	6.3E-03	8.6E-03	1.4E-02
Hazardous waste	20.7	3.2E-02	6.5E-03	3.5E-02	6.0E-02
Slag and ashes	320	7.7E-03	1.9E-02	5.6E-03	2.8E-03

Table 10.8

Weighting of waste flows from 33 cl beer packaging systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refer to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 128.2 litres of beer.

Waste category	Weighting factor	Refillable glass bottle [PET/FU]	Disposable glass bottle [PET/FU]	Aluminium can [PET/FU]	Steel can [PET/FU]
Bulk waste	1.1	6.3E-03	7.0E-03	9.5E-03	1.6E-02
Hazardous waste	1.1	3.5E-02	7.1E-03	3.8E-02	6.6E-02
Slag and ashes	1.1	8.5E-03	2.1E-02	6.1E-03	3.1E-03

10.3 Sensitivity analyses

Several sensitivity analyses are made on the LCA results from the different systems. The sensitivity analyses take into account emissions of CO_2, SO_2, NO_x and VOC. The various sensitivity analyses are described in section 2.13. The results are presented in the interpretation sections in chapters 3-6 (see, *e.g.*, Table 3.14) and - in more detail - in section 5.2.4 in Technical reports 1-4.

Electricity production

The electricity production is important for the results of this LCA. In the base case scenario, electricity production is responsible for more than half the net total CO_2 emissions and approximately half of the SO_2 and NO_x emissions from the aluminium and steel can systems.

Using the scenario with fragmented electricity markets - where the marginal production is based on natural gas in the Nordic countries and coal condensing in other countries - the emissions of SO_2 are reduced by nearly 25%. Emissions of CO_2 and NO_x from the aluminium system are reduced by 10-15%.

If the marginal is based on natural gas only, the SO_2 emissions are reduced by more than 50% for the aluminium can system. Emissions of CO_2 and NO_x are in this case reduced by approximately 30%.

Using the electricity scenario based on the average mix for European base-load electricity production, the CO_2 emissions are reduced by more than 30% for the aluminium can system. Emissions of NO_x are reduced by more than 20%. The emissions of SO_2, though, are increased by nearly 90%. The reason is that the SO_2 emissions are low from the modern coal-condensing technology represented in the base case scenario.

The aluminium cans may be produced and remelted in Sweden. For the next few years, the long-term marginal electricity production in Sweden may be old nuclear power, which cause much less emissions of CO_2, SO_2, and NO_X compared to coal condensing power (see section 2.7.3). If the marginal electricity is nuclear power, the net total CO_2 emissions from the aluminium can systems are reduced by more than half. The SO_2 and NO_x emissions are reduced by approximately half.

The effects on the emissions from the steel can system are similar to those on the emissions from the aluminium system. However, they are slightly smaller if calculated in percentages of the net total emissions.

The emissions from the glass bottle systems are also affected by the electricity scenario, although less than the can systems. Emissions of SO_2 from the refillable bottle system are reduced by nearly 30% if the marginal is based only on natural gas - compared to the over 50% reduction in the aluminium can system.

Packaging weight

The weight of the primary packaging has a limited effect on the LCA results. An increase by 20% in the refillable glass bottle means that the emissions are increased by 10-15%. If the weight of the aluminium can is increased by 20%, the effects are only slightly larger. It should be added that the actual uncertainty in the packaging weights is much less than 20%.

Recycling rates

The results are fairly sensitive to changes in collection rates. If the collection of aluminium cans is 98.5% instead of 90%, the emissions of CO_2, SO_2 and NO_x are reduced by 15-25%. However, the VOC emissions are not significantly affected (see chapter 5). If the collection rate of refillable glass bottles is 90% rather than 98.5%, the emissions of CO_2, SO_2, NO_x and VOC are increased by 40-80% (see chapter 3). However, such a low collection rate is not likely for refillable glass bottles in Denmark. The current collection rate is much higher (Jacobsen 1997).

The recycling rates are more important in this update than in the previous study. The reason is that we expand system boundaries and assume that recycled glass, aluminium and tinsteel will replace virgin material.

Discarded glass bottles

A change in the share of discarded glass bottles at the brewery has similar effects as a change in the collection rate. However, the uncertainty is smaller. The share of discarded glass bottles is unlikely to be more than 2-3%. For this reason, the effects on the emissions are unlikely to be as large as the ones discussed above.

Rate of cullets

The rate of cullets in the glass bottles has no effect on the LCA results. We have assumed that all broken glass that is available for recycling will be recycled. This means that if the broken glass is not replacing virgin raw materials in bottles for the Danish packaging system, they will replace virgin raw materials in other products.

Secondary aluminium

Just like the rate of cullets, the share of secondary aluminium in the aluminium cans and of the lids of steel cans has no effect on the LCA results. If the aluminium scrap is not recycled into the Danish packaging system, we assume that it will replace primary aluminium in another product.

Allocation

We avoid allocation in recycling through expansion of system boundaries. With this procedure, the assumption that recycled glass, aluminium and tinsteel will replace 100% virgin material is a key assumption. If we assume that recycled tinsteel will replace 50% virgin material and 50% steel scrap from other systems, the CO_2, SO_2, NO_x and VOC emissions of the steel can system are increased by 10-25%. The assumption might also be important for the aluminium can system. For green glass bottles, however, the assumption is not important.

Transport data

The distribution is fairly important for the total LCA results. If light trucks are used, rather than the medium and heavy trucks indicated by our data, the NO_x emissions from the refillable glass bottle system are increased by nearly 50%. Emissions of CO_2, SO_2 and VOC are increased by 15-25%. The effects on emissions from the aluminium and steel can systems are relatively small.

Omissions

The packaging systems have a large number of non-elementary inflows, *i.e.*, materials that are not traced back to the boundary between technosphere and nature. Furthermore, the retailer and the private transport home from the retailer are not included in the LCA. The sensitivity analyses presented in Technical reports 1-6 indicate that these omissions do not have a significant impact on the total CO_2, SO_2, NO_x and VOC emissions from the systems.

10.4 Conclusions

Final energy

The electricity demand is significantly lower for the refillable glass bottle than for the other packagings. The demand for fossil fuel at final use is significantly lower for the aluminium can.

Primary fuels

The demand for primary fossil energy depends strongly on the electricity production. This is particularly true for the aluminium and steel can systems. However, the fossil fuel demand is likely to be lower in the refillable glass bottle system than in the systems with disposable glass bottles and the steel can system. In this respect, this update confirms the results of the previous study. The demand for primary fossil fuel is significantly lower for the refillable glass bottle than for the aluminium can if the marginal electricity production is based on fossil fuel.

Metals

In the base case scenario, the demand for primary aluminium is less for the aluminium can than for the steel can. This confirms the results of the previous study. However, the difference is only significant at high recycling rates and under the assumption that the recycled aluminium from the packaging system replaces 100% primary aluminium.

If recycled steel from the packaging systems replace 100% primary steel, there is only a small difference in the net total demand for primary steel between the steel can and the glass bottles. This is different compared to the previous study, where the difference in iron demand was large.

Tin is mainly used in the steel can and, to a lesser extent, in the glass bottle caps. In this respect, the update confirms the results of the previous study.

Global warming

The global warming potential (GWP) of the packaging systems is mainly caused by CO_2 emissions (see, *e.g.*, Table 3.7). As indicated in section 10.2, the GWP of the refillable glass bottle is less than half the GWP of the disposable bottle in the base case. The difference compared to the steel can is more than a factor 2.5. The sensitivity analysis shows that the uncertainty in the CO_2 emissions from the electricity production is large in the steel can system, but we still conclude that the GWP is significantly lower for the refillable glass bottle than for the disposable glass bottle and the steel can (see Table 10.9). In this respect, the update also confirms the results of the previous study.

Table 10.9

Ranking order of the 33 cl beer packaging systems. This ranking is estimated based on the base case results, the dominance analysis, and the uncertainties investigated in the sensitivity analyses and in the assessments of data quality data gaps.

Environmental impacts	Refillable glass bottle	Disposable glass bottle	Aluminium can	Steel can
Global warming	1-2	2-4	1-3	3-4
Photochemical ozone	1-2	2-4	1-3	3-4
Acidification	1-2	3-4	1-2	3-4
Nutrient enrichment	1-2	3-4	1-2	3-4

The GWP of the refillable glass bottle is also less than half the GWP of the aluminium can in the base-case scenario. However, if the marginal electricity in the aluminium can system is mainly nuclear power - or another non-fossil technology - the difference in GWP between the refillable bottle and the aluminium can is small. From this we conclude that the difference between the refillable bottle and the aluminium can systems is significant only if the marginal electricity production to a large share is based on fossil fuel. This is still an adjustment compared to the conclusions of the previous study, where the GWP was slightly higher for the refillable glass bottle than for the aluminium can. This difference was estimated not to be significant, however (Wesnæs 1996).

There is a relatively small (20%) but fairly significant difference in GWP between the aluminium and steel can systems. The GWP from the aluminium production is likely to be larger in the steel can system because more aluminium is likely to be produced (see above). Furthermore, a significant amount of GWP is caused by tinplate production in the steel can system (see also section 11.4).

The difference in GWP between the disposable glass bottle, on one hand, and the steel and aluminium cans, on the other, is also relatively small. This difference is not significant due to the uncertainties in electricity production, collection rates etc.

POCP

The previous study identified no significant differences regarding the photochemical ozone formation potential of the different systems. On the basis of our sensitivity analysis, dominance analysis and assessments of data quality and data gaps, we estimate that the most important uncertainty is the POCP of unspecified VOC and hydrocarbon emissions. Approximately half of the net total POCP is caused by unspecified emissions of VOC and hydrocarbon (see, *e.g.*, Table 3.7), and the uncertainty in the POCP of these emissions is estimated to be +/-50% (see section 5.4.3 in Technical Reports 1-6). Here, we conclude that the POCP is significantly lower for the refillable glass bottle than for the disposable bottle and the steel can. However, the difference between the refillable glass bottle and the aluminium can is not quite large enough to be significant.

The relatively small difference in POCP between the aluminium and steel can systems is still fairly significant. The POCP from the aluminium production and the distribution is likely to be larger in the steel can system because more aluminium is likely to be produced and because the steel cans are a little heavier than the aluminium cans. In addition, a significant amount of POCP is caused by tinplate production in the steel can system.

The small difference in POCP between the disposable glass bottle, on one hand, and the steel and aluminium cans, on the other, is not significant due to the uncertainties in the POCP of unspecified VOC and hydrocarbon emissions.

Acidification

The acidification potential of the packaging systems is mainly caused by NO_X and SO_2 emissions (see, *e.g.*, Table 3.7). In the base case, the acidification potential is nearly three times lower for the refillable glass bottle than for the disposable bottle and the steel can. The uncertainty in the NO_X and SO_2 emissions from the electricity production in the steel can system is large, but the difference is still significant. This is an adjustment compared to the conclusions of the previous study.

The acidification potential of the refillable glass bottle is less than half the acidification potential of the aluminium can in the base-case scenario. However, if the marginal electricity in the aluminium can system is mainly based on natural gas - or non-fuel technology - the difference in acidification between these packaging systems is relatively small. From this we conclude that the difference between the refillable bottle and the aluminium can is significant only if the marginal electricity production to a large share is based on fossil fuel other than natural gas. This is an adjustment compared to the previous study, where the acidification potential was slightly (and insignificantly) higher for the refillable glass bottle than for the aluminium can.

Based on the sensitivity analyses etc., we estimate that the acidification potential is also significantly lower for the aluminium can than for the disposable glass bottle and steel can. In the comparison between steel and aluminium cans, the same arguments apply as in the GWP comparison. This is also an adjustment compared to the previous study.

The difference in acidification between the disposable glass bottle and the steel can is small and not significant. This confirms the conclusions from the previous study.

Nutrification

The nutrification potential of the packaging systems is mainly caused by NO_X emissions (see, *e.g.*, Table 3.7). In the base case, the nutrification potential is 2-3 times lower for the refillable glass bottle than for the disposable bottle and the steel can. Although the uncertainties in NO_X emissions from the marginal electricity production is large, we can conclude that the nutrification potential is significantly lower for the refillable glass bottle than for the disposable glass bottle and the steel can. This is different from the previous study, where there was no significant difference between the nutrification potential of these packaging systems.

The nutrification potential of the refillable glass bottle is sligthly more than half the potential of the aluminium can in the base-case scenario. However, if the marginal electricity in the aluminium can system is mainly nuclear power, the difference in nutrification between the refillable bottle and the aluminium can is small. From this we conclude that the difference between the refillable bottle and the aluminium can systems is significant only if the marginal electricity production to a large share is based on the combustion of fuel. This is still a change compared to the conclusions of the previous study, where the nutrification potential was higher for the refillable glass bottle than for the aluminium can. This difference was estimated to be nearly significant.

We estimate that the nutrification potential is significantly lower for the aluminium can than for the disposable glass bottle and the steel can. In the comparison between steel and aluminium cans, the same arguments apply as in the POCP comparison. The difference between the disposable bottle and the steel can is not significant.

Waste

The glass bottles generate less bulk waste than the can systems. This is different from the previous study, where the disposable glass bottles generated the largest amount of bulk waste.

In the base case scenario, disposable glass bottles generate less hazardous waste than the other packagings. The largest amount is generated by the steel cans. This conclusion is a moderate adjustment compared to the previous study, where there was a very small difference between the glass bottles. The difference between the steel and the aluminium can was also very small in the previous study.

Steel cans generate less slag and ashes than the other packagings. The disposable glass bottle generates the most. This is also a moderate adjustment compared to the previous study, where the amount of slag and ashes was slightly lower for the aluminium can than for the steel can, and where the difference between the steel can and the refillable glass bottle was small.

It should be added that if the marginal electricity is mainly nuclear power, the refillable glass bottle generates less radioactive waste than the disposable glass bottle. The reason is that the electricity demand is significantly lower for the refillable glass bottle than for the disposable bottle. For the same reason, the amount of radioactive waste is significantly higher for the aluminium and steel can systems than for the glass bottles (see Table 10.1).

11 Comparison of 50 cl beer cans

11.1 Introduction

Systems compared

The LCAs summarised above include the assessment of systems with two different 50 cl cans:

- aluminium cans, and
- steel cans.

Limitations

This chapter presents an environmental comparison of the two packaging systems. As in the previous chapter, the comparison is limited to the environmental impacts covered by the LCAs. This means that, *e.g.*, work environment and health impacts from use and misuse of the packaging are not included in the comparison.

11.2 Comparing base case scenarios

Energy at final use

Table 11.1 presents the final use of fuel and electricity, as opposed to the demand for primary energy. This means that, *e.g.*, the fossil fuel demand do not include fossil fuel used for electricity production.

The results indicate that the electricity demand is the same for the two systems, but that the fossil fuel demand at final use is nearly the double for the steel can compared to the aluminium can. The demand for renewable fuel and other energy carriers is relatively small in both systems.

Table 11.1
Net total energy demand at final use for 50 cl beer can systems in the base case. Functional unit: packaging and distribution of 128.2 litres of beer.

Energy demand	Unit	Aluminium can	Steel can
Electricity	kWh	2.99E+01	3.01E+01
Fossil fuel	MJ	1.13E+02	2.02E+02
Renewable fuel	MJ	1.45E+00	1.42E+00
Heat etc.	MJ	-8.44E-01	1.43E+01

Primary energy

In the base case scenario, the demand for all primary fossil energy resources is lower for the aluminium can than for the steel can (see Tables 10.2-3). The difference in the demand for oil and coal is less than in the previous study, but the difference in the demand for natural gas is a somewhat larger.

Most of the coal is used for production of electricity which in turn is used in, *e.g.*, the production of primary aluminium and cans. In the steel can system, a significant share of the coal is also used as coke for pig iron production.

Metals demand

The demand for aluminium is approximately 20% larger for the steel can. As indicated in the previous chapter, this is explained by the fact that the aluminium lid on the steel can is oxidised at steel recycling, and thus the aluminium is lost.

The steel can demands more iron and tin than the aluminium can because these resources are used for the production of tinsteel. On the other hand, manganese resources are used in the production of aluminium for aluminium cans.

Table 11.2

Normalisation of net total depletion of selected resources for 50 cl beer can systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 128.2 litres of beer. The unit of the normalisation reference is kg per person and year.

Resource	Normalisation Reference	Aluminium can [PE/FU]	Steel can [PE/FU]
Oil	590	4.2E-03	5.2E-03
Coal	931	1.8E-02	3.1E-02
Brown coal	250	6.6E-04	1.1E-03
Natural gas	310	4.2E-03	8.4E-03
Aluminium	3.4	1.8E-01	2.2E-01
Iron	100	2.2E-07	6.8E-03
Manganese	1.8	5.2E-03	1.1E-07
Tin	0.04	0	5.8E-01

Table 11.3

Selected weighting results for net total resource depletion of 50 cl beer can systems in the base case. The unit is person-reserve (PR) per functional unit (FU). The person-reserve is the fraction of known global reserves per person in the world in 1990 (Hauschild & Wenzel 1998). The functional unit is the packaging and distribution of 128.2 litres of beer.

Resource	Weighting factors	Aluminium can [PR/FU]	Steel can [PR/FU]
Oil	0.023	9.7E-05	1.2E-04
Coal	0.0058	1.1E-04	1.8E-04
Brown coal	0.0026	1.7E-06	2.9E-06
Natural gas	0.016	6.8E-05	1.3E-04
Aluminium	0.0051	9.3E-04	1.1E-03
Iron	0.0085	1.9E-09	5.7E-05
Manganese	0.012	6.2E-05	1.4E-09
Tin	0.037	0	2.1E-02

Global warming etc.

In the base case scenario, the potential global warming (GWP), acidification, nutrification and photochemical ozone formation are all approximately 20% less for the aluminium can system than for the steel can system (see Tables 10.4-6). The difference in GWP is due to the larger amount of coal used, *e.g.*, at production of pig iron.

Table 11.4

Comparison of net total potential environmental impacts for 50 cl beer can systems in the base case. The table presents characterisation results for the non-toxicological impacts. Functional unit: packaging and distribution of 128.2 litres of beer.

Environmental impacts	Unit	Aluminium can	Steel can
Global warming	kg CO_2-eq	3.8E+01	4.7E+01
Photochemical ozone formation	kg C_2H_4-eq	1.5E-02	1.9E-02
Acidification	kg SO_2-eq	1.8E-01	2.2E-01
Nutrient enrichment	kg NO_3-eq	1.8E-01	2.2E-01

Table 11.5
Normalisation of net total potential environmental impacts for 50 cl beer can systems in the base case. The unit of the normalised impacts is person equivalents (PE) per functional unit (FU). The person equivalents refers to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 128.2 litres of beer.

Environmental impacts	Normalisation reference	Aluminium can [PE/FU]	Steel can [PE/FU]
Global warming	8700	4.3E-03	5.4E-03
Photochemical ozone formation	20	7.4E-04	9.4E-04
Acidification	124	1.4E-03	1.7E-03
Nutrient enrichment	298	6.0E-04	7.3E-04

Table 11.6
Weighting of net total potential environmental impacts for 50 cl beer can systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refers to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 128.2 litres of beer.

Environmental impacts	Weighting factor	Aluminium can [PET/FU]	Steel can [PET/FU]
Global warming	1.2	5.6E-03	7.0E-03
Photochemical ozone formation	1.2	8.9E-04	1.1E-03
Acidification	1.3	1.8E-03	2.3E-03
Nutrient enrichment	1.3	7.1E-04	8.7E-04

Waste

In the base case scenario, the aluminium can generates slightly more than half as much of bulk waste and hazardous waste as the steel can (see Tables 11.7-8). On the other hand, the amount of slag & ashes is more than double the amount of steel cans.

Table 11.7
Normalisation of waste flows from 50 cl beer can systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 128.2 litres of beer. The unit of the normalisation reference is kg per person and year.

Waste category	Normalisation Reference	Aluminium can [PE/FU]	Steel can [PE/FU]
Bulk waste	1350	6.9E-03	1.2E-02
Hazardous waste	20.7	2.9E-02	5.2E-02
Slag and ashes	320	4.7E-03	2.2E-03

Table 11.8
Weighting of waste flows from 50 cl beer can systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refers to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 128.2 litres of beer.

Waste category	Weighting factor	Aluminium can [PET/FU]	Steel can [PET/FU]
Bulk waste	1.1	7.6E-03	1.3E-02
Hazardous waste	1.1	3.1E-02	5.7E-02
Slag and ashes	1.1	5.1E-03	2.5E-03

11.3 Sensitivity analyses

As stated in the previous chapter, the sensitivity analyses take into account emissions of CO_2, SO_2, NO_x and VOC. The various sensitivity analyses are described in section 2.13. The results are presented in the interpretation sections in chapters 5 and 6 (see, *e.g.*, Table 5.14) and - in more detail - in section 5.2.4 in Technical reports 3 and 4.

Electricity production

The electricity production is important for the results on the aluminium and steel can systems. However, since the electricity demand is the same in both systems (see Table 11.1), the assumptions on the electricity production technology do not affect the comparison between the systems.

Packaging weight

As described in the previous chapter, the weight of the primary packaging had limited effect on the LCA results. An increase by 20% in the weight of the aluminium can means that the CO_2, SO_2, NO_x and VOC emissions are increased by 10-25%.

Recycling rates

The results are fairly sensitive to changes in collection rates. If the collection of aluminium cans is 98.5% instead of 90%, the emissions of CO_2, SO_2 and NO_x are reduced by 15-25%. However, the emissions caused by the steel can system would also be reduced.

Secondary aluminium

As indicated in the previous chapter, the share of secondary aluminium in the aluminium cans and the lids of steel cans has no effect on the LCA results.

Allocation

If we assume that recycled tinsteel will replace 50% virgin material and 50% steel scrap from other systems, the CO_2, SO_2, NO_x and VOC emissions of the steel can system are increased by 10-25%. This assumption might also be important for the aluminium can system, but the significance is difficult to estimate, since no specific data on the share of secondary aluminium in the aluminium can were available within this project.

Transport data

The transport data are less important for the results of the steel and aluminium can systems than for the glass bottle systems. If light trucks are used - rather than the medium and heavy trucks indicated by our data - the CO_2, SO_2, NO_x and VOC emissions from the aluminium and steel can systems are increased by less than 15%. Furthermore, the effects on the aluminium can system would be similar to the effects on the steel can system. Hence, the transport data have virtually no effect on the comparisons between the two systems.

Omissions

The packaging systems have a large number of non-elementary inflows, *i.e.*, materials that are not traced back to the boundary between technosphere and nature. Furthermore, the retailer and the private transport home from the retailer are not included in the LCA. The sensitivity analyses presented in Technical reports 1-6 indicate that these omissions do not have a significant impact on the total CO_2, SO_2, NO_x and VOC emissions from the systems. In particular, the aluminium and steel cans have little effect on the energy demand of the retailer and the private transport.

11.4 Conclusions

Final energy

It is evident from Table 11.1 that the demand for energy at final use is lower for the aluminium can than for the steel can. This difference is significant.

Primary fuel

The demand for primary fossil energy is also lower for the aluminium can than for the steel can. In this respect, this update confirms the results of the previous study. However, the difference is slightly less than in the previous study.

Metals

In the base case scenario, there is a small difference in the demand for primary aluminium between the steel can and the aluminium can. This is also a confirmation of the results from the previous study. However, the difference is only significant under the assumption that the recycled aluminium from the packaging system replaces 100% primary aluminium.

Global warming etc.

The potential global warming, acidification, nutrification and photochemical ozone formation are approximately 20% less for the aluminium can than for the steel can. These differences are less than in the previous study. However, the sensitivity analyses indicate that the small differences are still fairly significant. This is supported by the fact that there are large similarities between the systems compared. Both systems are based on disposable, light weight, metal packagings with a high collection rate. The production of primary aluminium is also important for the total LCA results of both systems. When the recycling rate is high, the demand for primary aluminium is in the same order of magnitude in both systems. The main difference is the tinsteel production in the steel can system. It can be concluded that if the recycling rate is high and if recycled aluminium and steel replace 100% primary metals, there is a relatively small but significant difference in the potential global warming, acidification, nutrification and photochemical ozone formation of the systems (see Table 11.9).

Table 11.9
Ranking order of the 50 cl beer packaging systems. This ranking is estimated based on the base case results, the dominance analysis, and the uncertainties investigated in the sensitivity analyses and in the assessments of data quality data gaps.

Environmental impacts	Aluminium can	Steel can
Global warming	1	2
Photochemical ozone formation	1	2
Acidification	1	2
Nutrient enrichment	1	2

Waste

In the base case scenario, both systems generate more bulk waste according to this update than in the previous study. The relations between the systems are still the same, however. The aluminium cans generate more slag and ashes than in the previous study. Both can systems generate more hazardous waste than in the previous study. For the steel can system the increase is quite large: a factor six. The difference compared to the previous study might depend on a more complete set of data being used in the update rather than on changes in the real systems.

12 Comparison of 33 cl soft-drink packagings

12.1 Introduction

Systems compared

The LCAs summarised above include the assessment of systems with three different 33 cl packagings for carbonated soft drinks:

- 33 cl disposable, colourless glass bottles
- 33 cl aluminium cans, and
- 33 cl steel cans.

Limitations

This chapter presents an environmental comparison of the four packaging systems. The comparison is limited to the environmental impacts covered by the LCAs. This means that, *e.g.*, work environment and health impacts from use and misuse of the packaging are not included in the comparison.

Extrapolation

The studies reported above also include an LCA of 25 cl refillable glass bottles for soft drinks. The results on that bottle and the results on the 33 cl refillable green glass bottle for beer are used to discuss the environmental impacts of a hypothetical 33 cl refillable colourless glass bottle for soft drinks (see section 12.3).

12.2 Comparing base case scenarios

The comparison between the disposable glass bottle and the aluminium and steel cans for carbonated soft drink is similar to the comparison of 33 cl beer packagings.

Energy at final use

The total amounts of fuel and electricity used in the processes and transports are compared in Table 12.1. It should be noted that the table presents the final use of fuel and electricity, not the demand for primary energy. This means that, *e.g.*, the fossil fuel demand does not include fossil fuel used for electricity production.

In the base case, the total energy demand at final use is lower for the refillable glass bottle and the aluminium can than for the competing systems.

Electricity demand

The electricity demand is high for the aluminium and steel cans. Approximately half of this electricity is used in the production of primary aluminium and in can production.

Table 12.1
Net total energy demand at final use for small soft drink packaging systems in the base case. Functional unit: packaging and distribution of 72.3 litres of softdrink.

Energy demand	Unit	Disposable glass bottle	Aluminium can	Steel can
Electricity	kWh	9.72E+00	2.17E+01	2.21E+01
Fossil fuel	MJ	1.98E+02	7.15E+01	1.24E+02
Renewable fuel	MJ	1.44E+00	1.09E+00	1.05E+00
Heat etc.	MJ	-4.79E+00	-6.34E-01	8.98E+00

Fossil fuel demand

The demand for fossil fuel at final use is low for the aluminium can. However, it is high in the disposable glass bottle system. The main reason is the fuel demand at production of glass and raw materials (see the dominance analysis in Technical report 2).

Other energy carriers

The demand for renewable fuel and other energy carriers is small in all systems. Two systems produce a small net surplus of steam and/or other energy carriers.

Primary energy

The demand for primary fossil energy resources is presented in Tables 12.2-3. The demand for all primary fossil fuels is lower for the glass bottle than for the competing packagings. This is a large difference compared to table 12.1. The reason is that the electricity production is based on coal in the base case scenario.

The steel can has the highest demand for all fossil fuels. Most of the coal is used for production of electricity which in turn is used in, *e.g.*, the production of primary aluminium and tinsteel cans. A significant share of the coal is also used as coke for pig iron production.

Table 12.2

Normalisation of net total depletion of selected resources for small soft-drink packaging systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drink. The unit of the normalisation reference is kg per person and year.

Resource	Normalisation Reference	Disposable glass bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Oil	590	2.2E-03	2.7E-03	3.5E-03
Coal	931	6.5E-03	1.3E-02	2.1E-02
Brown coal	250	2.7E-04	4.7E-04	7.5E-04
Natural gas	310	5.4E-04	2.8E-03	5.4E-03
Aluminium	3.4	4.8E-06	1.3E-01	1.9E-01
Iron	100	3.9E-03	1.6E-07	3.9E-03
Manganese	1.8	2.4E-08	3.8E-03	7.9E-08
Tin	0.04	2.4E-02	0	3.6E-01

Table 12.3

Selected weighting results for net total resource depletion of small soft-drink packaging systems in the base case. The unit is person-reserve (PR) per functional unit (FU). The person-reserve is the fraction of the known global reserves per person in the world in 1990 (Hauschild & Wenzel 1998). The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Resource	Weighting factors	Disposable glass bottle [PR/FU]	Aluminium can [PR/FU]	Steel can [PR/FU]
Oil	0.023	5.0E-05	6.2E-05	8.1E-05
Coal	0.0058	3.8E-05	7.3E-05	1.2E-04
Brown coal	0.0026	7.1E-07	1.2E-06	1.9E-06
Natural gas	0.016	8.6E-06	4.5E-05	8.6E-05
Aluminium	0.0051	2.4E-08	6.8E-04	9.6E-04
Iron	0.0085	3.4E-05	1.4E-09	3.3E-05
Manganese	0.012	2.9E-10	4.5E-05	9.1E-10
Tin	0.037	8.9E-04	0	1.3E-02

Metals demand

The demand for aluminium is higher in the steel can systems than in the aluminium can system. As indicated above, the same relation was valid in the previous study. The reason is that the aluminium lid on the steel can is oxidised in the steel recycling process.

The demand for iron is as large in the glass bottle systems as in the steel can system. This is partly due to our criteria for defining system boundaries. The tinsteel caps of the glass bottles end up at waste incineration. It can be assumed that half of the steel is recovered from the ashes and recycled, but this flow is so small (less than 1% of primary packaging weight) that the systems boundaries were not expanded to include this recycling.

Manganese is used as an alloy in the aluminium can, and tin is used for producing tinsteel. The tin demand is higher for the steel can than for the glass bottles, since the tin is not recovered at steel can recycling.

Global warming

In the base case scenario, the global warming potential (GWP) of the steel can system is approximately 25% higher than the GWP of the disposable glass bottle and the aluminium can (see Tables 12.4-6).

Table 12.4

Comparison of net total potential environmental impacts for small soft-drink packaging systems in the base case. The table presents characterisation results non-toxicological impacts. Functional unit: packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Unit	Disposable glass bottle	Aluminium can	Steel can
Global warming	kg CO_2-eq	2.5E+01	2.7E+01	3.3E+01
Photochemical ozone formation	kg C_2H_4-eq	1.0E-02	9.7E-03	1.2E-02
Acidification	kg SO_2-eq	1.5E-01	1.2E-01	1.5E-01
Nutrient enrichment	kg NO_3-eq	1.6E-01	1.2E-01	1.5E-01

Table 12.5

Normalisation of net total potential environmental impacts for small soft-drink packaging systems in the base case. The unit of the normalised impacts is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Normalisation reference	Disposable glass bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Global warming	8700	2.8E-03	3.1E-03	3.8E-03
Photochemical ozone formation	20	5.2E-04	4.8E-04	6.2E-04
Acidification	124	1.2E-03	9.9E-04	1.2E-03
Nutrient enrichment	298	5.3E-04	4.1E-04	5.1E-04

Table 12.6

Weighting of net total potential environmental impacts for small soft-drink packaging systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refers to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Weighting factor	Disposable glass bottle [PET/FU]	Aluminium can [PET/FU]	Steel can [PET/FU]
Global warming	1.2	3.7E-03	4.0E-03	4.9E-03
Photochemical ozone formation	1.2	6.2E-04	5.8E-04	7.4E-04
Acidification	1.3	1.6E-03	1.3E-03	1.6E-03
Nutrient enrichment	1.3	6.4E-04	4.9E-04	6.1E-04

POCP

The base case scenario results indicate that the steel can contributes slightly more to the potential photochemical formation of ozone (POCP) than the competing packagings. However, the difference between the systems is small and not significant.

Acidification and nutrification

The results also indicate that the disposable glass bottle and the steel can contribute somewhat more to the potential acidification and nutrification than the aluminium can. These differences are also small and should not be considered to be significant.

Waste

The disposable glass bottle generates less bulk waste and hazardous waste than the competing packagings (see Tables 10.7-8). The steel can generates more hazardous waste than the other packagings. For slags & ashes, the relations are the opposite.

Table 12.7

Normalisation of waste flows from small soft-drink packaging systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refers to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drink. The unit of the normalisation reference is kg per person and year.

Waste category	Normalisation Reference	Disposable glass bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Bulk waste	1350	2.7E-03	4.9E-03	8.2E-03
Hazardous waste	20.7	3.0E-03	2.0E-02	3.4E-02
Slag and ashes	320	1.1E-02	3.1E-03	1.6E-03

Table 12.8

Weighting of waste flows from small soft-drink packaging systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refers to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Waste category	Normalisation Reference	Disposable glass bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Bulk waste	1.1	2.9E-03	5.3E-03	9.0E-03
Hazardous waste	1.1	3.3E-03	2.1E-02	3.7E-02
Slag and ashes	1.1	1.2E-02	3.5E-03	1.7E-03

12.3 Extrapolation to 33 cl refillable glass bottle

There are only small differences between the 33 cl soft drink packagings and the 33 cl beer packagings. The soft drink cans differ from the beer cans in the amount of inner coatings. There are also some differences in the energy demand for producing steel cans for soft drink and beer. However, these differences have little effect on total LCA results (see the sensitivity analysis in chapter 6).

A larger share of recycled glass is used for the production of green bottles for beer than for colourless soft drink bottles. Since we assume that all glass available for recycling will be recycled, this difference is not significant for the LCA results.

The energy demand reported for the washing and filling of the green 33 cl glass bottle is almost double the corresponding figure for the colourless 25 cl bottle, if calculated per 1000 bottles. It has not been ascertained whether this difference is due to differences in beverage, in washing technology or in bottle size. However, it seems clear that the washing of a hypothetical colourless 33 cl glass bottle would not demand more energy than the washing of the current green bottle.

All this indicates that the results for a hypothetical 33 cl colourless bottle would not be significantly higher than the results for the 33 cl green refillable glass bottle. It also indicates that the comparison made in chapter 10 between the 33 cl refillable glass bottle and the competing packagings can also be applied on a hypothetical 33 cl refillable glass bottle for carbonated soft drinks.

12.4 Sensitivity analyses

As stated in the previous chapters, the sensitivity analyses take into account emissions of CO_2, SO_2, NO_x and VOC. The various sensitivity analyses are described in section 2.13. The results are presented in the interpretation sections in chapters 3-6 (see, *e.g.*, Table 3.14) and - in more detail - in section 5.2.4 in Technical reports 1-4.

Electricity production

As indicated, *e.g.*, in section 10.3, the electricity production is important for the results of this LCA. In the base case scenario, electricity production is responsible for more than half of the net total CO_2 emissions and approximately half of the SO_2 and NO_X emissions from the aluminium and steel can systems.

Using the scenario with fragmented electricity markets the emissions of SO_2 from the aluminium system are reduced by nearly 25% for the aluminium can system. Emissions of CO_2 and NO_X from this system are reduced by 10-15%.

If the marginal is based on natural gas only, the SO_2 emissions are reduced by more than 50% for the aluminium can system. Emissions of CO_2 and NO_X are in this case reduced by approximately 30%.

Using the electricity scenario based on the average mix for European base-load electricity production, the CO_2 emissions are reduced by more than 30% for the aluminium can system. Emissions of NO_X are reduced by more than 20%. The emissions of SO_2, though, are increased by nearly 90%.

If the marginal electricity production is nuclear power - or another non-combustion technology - the net total CO_2 emissions from the aluminium can system would be reduced by more than half. The net total emissions of SO_2 and NO_X would be reduced by approximately half.

The effects on the emissions from the steel can system are similar to those on the emissions from the aluminium can system. However, they are slightly smaller if calculated in percentages of the net total emissions. The emissions from the glass bottle systems are also affected by the electricity scenario, but less than the can systems.

Packaging weight

As discussed in section 10.3, the weight of the primary packaging has a limited effect on the LCA results.

Recycling rates

The results are fairly sensitive to changes in collection rates. If the collection of aluminium cans is 98.5% instead of 90%, the emissions of CO_2, SO_2 and NO_X are reduced by 15-25%. However, the VOC emissions are not significantly affected (see chapter 5). If the collection rate of (hypothetical) refillable glass bottles is 90% rather than 98.5%, the emissions of CO_2, SO_2, NO_X and VOC are increased by 40-80% (see chapter 3). However, such a low collection rate is not likely for Danish refillable glass bottles (see section 10.3).

Discarded glass bottles

A change in the share of discarded glass bottles at the brewery is likely to have smaller effects than a change in the collection rate (see section 10.3).

Use of recycled material

The rate of cullets in the glass bottles has no effect on the LCA results, nor has the share of secondary aluminium in the aluminium cans and in the lids of steel cans (see section 10.3).

Allocation

The assumption that recycled glass, aluminium and tinsteel from the packaging systems will replace 100% virgin material is fairly important. If we assume that recycled tinsteel will replace 50% virgin material and 50% steel scrap from other systems, the CO_2, SO_2, NO_X and VOC emissions of the steel can system are increased by 10-25%. This assumption might also be important for the aluminium can system. For glass bottles, however, the assumption is not very important.

Transport data

The distribution is fairly important for the total LCA results. If light trucks are used, rather than the medium and heavy trucks indicated by our data, the NO_X emissions from the (hypothetical) refillable glass bottle system are increased by approximately 50%. Emissions of CO_2, SO_2 and VOC are increased by 15-25%. The effects on emissions from the aluminium and steel can systems are relatively small.

Omissions

The packaging systems have a large number of non-elementary inflows, *i.e.*, materials that are not traced back to the boundary between technosphere and nature. Furthermore, the retailer and the private transport home from the retailer are not included in the LCA. The sensitivity analyses presented in Technical reports 1-6 indicate that these omissions do not have a significant impact on the total CO_2, SO_2, NO_X and VOC emissions from the systems.

12.5 Conclusions

There are some differences between beer packagings and soft-drink packagings. These differences include the amount of coatings in the aluminium and steel cans and the amount of broken glass in the raw materials used for producing glass bottles. However, these differences are not important for the total LCA results, and they do not affect the conclusions. Hence, the conclusions from this comparison are similar to the conclusions on 33 cl beer packagings.

Final energy

The demand for fossil fuel at final use is significantly lower for the aluminium can. The electricity demand would probably be significantly lower for a 33 cl refillable glass bottle.

Primary fuels

The demand for primary fossil energy depends strongly on the electricity production. This is particularly true for the aluminium and steel can systems. However, the fossil fuel demand is likely to be lower in the (hypothetical) refillable glass bottle system than in the systems with disposable glass bottles and the steel can system. The demand for primary fossil fuel is also probably significantly lower for the refillable glass bottle than for the aluminium can if the marginal electricity production is based on fossil fuel.

In this respect, our results differ slightly from the results of the previous study. However, in the previous study packagings of different sizes were compared. This means that, *e.g.*, the 25 cl refillable glass bottle was compared to the 33 cl aluminium can.

Metals

In the base case scenario, the demand for primary aluminium is less for the aluminium can than for the steel can. This confirms the results of the previous study. However, the difference is only significant at high recycling rates and under the assumption that the recycled aluminium from the packaging system replaces 100% primary aluminium.

If recycled steel from the packaging systems replaces 100% primary steel, there is only a small difference in the net total demand for primary steel between the steel can and the glass bottles. This is different compared to the previous study.

Tin is mainly used in the steel can and, to a lesser extent, in the glass bottle caps. In the previous study tinplate was not used for the caps of disposable glass bottles for soft drink.

Global warming

In the base case scenario, the global warming potential (GWP) is slightly lower for the disposable glass bottle and the aluminium can than for the steel can. The difference is not significant, however. The GWP of the hypothetical 33cl refillable glass bottle would probably be significantly lower than the disposable glass bottle and the steel can. It would probably also be significantly lower than the GWP of the aluminium can if the electricity production was based on fossil fuel (see Table 12.9 and section 10.4). In this respect, the update differs from the results of the previous study, where the GWP of the aluminium can was slightly lower than the GWP of the refillable glass bottle and significantly lower than the GWP of the disposable glass bottle.

Table 12.9

Ranking order of the 33 cl soft-drink packaging systems. This ranking is estimated based on the base case results, the dominance analysis, and the uncertainties investigated in the sensitivity analyses and in the assessments of data quality data gaps.

Environmental impacts	Hypothetical refillable 33 cl glass bottle	Disposable glass bottle	Aluminium can	Steel can
Global warming	1-2	2-4	1-3	3-4
Photochemical ozone	1-2	2-4	1-3	3-4
Acidification	1-2	3-4	1-2	3-4
Nutrient enrichment	1-2	3-4	1-2	3-4

POCP

The previous study identified no significant differences regarding the photochemical ozone formation potential of the different systems. Based on our dominance analysis and data quality assessment, we estimate that the relatively small difference in POCP between the aluminium and steel can systems is fairly significant (see section 11.4 for an explanation).

The POCP would probably be significantly lower for the hypothetical 33 cl refillable glass bottle than for the disposable glass bottle and the steel can. The difference between this hypothetical bottle and the aluminium can is not quite significant, however (see also section 10.4).

Acidification and nutrification

The acidification and nutrification potentials are significantly lower for the aluminium can than for the steel can and the disposable glass bottle. The hypothetical refillable glass bottle would probably contribute significantly less than the disposable glass bottle and the steel can to acidification and nutrification (see also section 10.4).

Waste

The disposable glass bottle generates less bulk waste than the can systems. This is different from the previous study, where the disposable glass bottles generated the largest amount of bulk waste.

In the base case scenario, disposable glass bottles generate less hazardous waste than the other packagings. The largest amount is generated by the steel cans. This confirms the results of the previous study.

Steel cans generate less slag & ashes than the other packagings. The disposable glass bottle generates the most. This is a moderate adjustment compared to the previous study.

It can be added that if the marginal electricity is mainly nuclear power, the amount of radioactive waste is significantly higher for the aluminium and steel can systems than for the glass bottles. The reason is that the electricity demand is significantly higher (see Table 12.1).

13 Comparison of 50 cl soft-drink packagings

13.1 Introduction

Systems compared

The LCAs summarised above include the assessment of systems with four different 50 cl packagings for carbonated soft drinks:

- refillable PET bottles,
- disposable PET bottles,
- aluminium cans, and
- steel cans.

Limitations

This chapter presents an environmental comparison of the four packaging systems. Like in the previous chapters, the comparison is limited to the environmental impacts covered by the LCAs. This means that, *e.g.*, work environment and health impacts from use and misuse of the packaging are not included in the comparison.

13.2 Comparing base case scenarios

Energy at final use

The total amounts of fuel and electricity used in the processes and transports are compared in Table 13.1. It should be noted that the Table presents the final use of fuel and electricity, not the demand for primary energy. This means that, *e.g.*, the fossil fuel demand does not include fossil fuel used for electricity production.

In the base case, the total energy demand at final use is lower for the refillable PET bottle than for the competing systems.

Electricity demand

The electricity demand is high for the aluminium and steel cans. Approximately half of this electricity is used in the production of primary aluminium and in cans.

Fossil fuel demand

The demand for fossil fuel at final use is low for the refillable PET bottle and the aluminium can. However, it is high in the disposable PET bottle system. The main reason for this difference is the large demand for oil and natural gas as fuel and raw material in the production of PET resins.

Other energy carriers

The demand for renewable fuel and other energy carriers is small in all systems. Three systems produce quite a small net surplus of steam and/or other energy carriers.

Table 13.1

Net total energy demand at final use for 50 cl soft-drink packaging systems in the base case. Functional unit: packaging and distribution of 72.3 litres of soft drink.

Energy demand	Unit	Refillable PET bottle	Disposable PET bottle	Aluminium can	Steel can
Electricity	kWh	2.68E+00	4.52E+00	1.69E+01	1.70E+01
Fossil fuel	MJ	6.22E+01	2.80E+02	6.37E+01	1.14E+02
Renewable fuel	MJ	3.17E-01	8.65E-01	8.19E-01	8.00E-01
Heat etc.	MJ	-3.57E-01	-3.27E-01	-4.76E-01	8.08E+00

Primary energy

The demand for primary fossil energy resources in the base case scenario is presented in Tables 13.2-3. The demand for all primary fossil fuels is lower for the refillable bottle than for the competing packagings. The results indicate that the difference is fairly large. For oil and natural gas, the aluminium can is rated second. However, the oil demand is 50% higher than for the refillable bottle, and the demand for natural gas is more than double that of the refillable bottle.

Table 13.2

Normalisation of net total depletion of selected resources for 50 cl soft-drink packaging systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drink. The unit of the normalisation reference is kg per person and year.

Resource	Normalisation Reference	Refillable PET bottle [PE/FU]	Disposable PET bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Oil	590	1.6E-03	5.4E-03	2.4E-03	2.9E-03
Coal	931	1.7E-03	3.9E-03	1.0E-02	1.7E-02
Brown coal	250	7.4E-05	1.3E-04	3.7E-04	6.2E-04
Natural gas	310	1.1E-03	4.3E-03	2.4E-03	4.7E-03
Aluminium	3.4	1.3E-05	6.4E-05	1.0E-01	1.2E-01
Iron	100	7.6E-08	2.7E-07	1.3E-07	3.8E-03
Manganese	1.8	6.8E-06	6.2E-05	2.9E-03	6.5E-08
Tin	0.04	0	0	0	3.3E-01

Table 13.3
Selected weighting results for net total resource depletion of 50 cl soft-drink packaging systems in the base case. The unit is person-reserve (PR) per functional unit (FU). The person-reserve is the fraction of the known global reserves per person in the world in 1990 (Hauschild & Wenzel 1998). The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Resource	Weighting factors	Refillable PET bottle [PR/FU]	Disposable PET bottle [PR/FU]	Aluminium can [PR/FU]	Steel can [PR/FU]
Oil	0.023	3.6E-05	1.2E-04	5.5E-05	6.7E-05
Coal	0.0058	9.7E-06	2.1E-05	6.0E-05	9.7E-05
Brown coal	0.0026	1.9E-07	3.1E-07	9.6E-07	1.6E-06
Natural gas	0.016	1.8E-05	6.8E-05	3.8E-05	7.6E-05
Aluminium	0.0051	6.6E-08	3.3E-07	5.3E-04	6.3E-04
Iron	0.0085	6.5E-10	2.3E-09	1.1E-09	3.2E-05
Manganese	0.012	8.2E-08	7.4E-07	3.5E-05	7.4E-10
Tin	0.037	0	0	0	1.2E-02

Coal demand

For coal and brown coal, the disposable PET bottle is rated second. The coal demand is nearly double that of the refillable bottle. The brown coal demand is more than double that of the refillable bottle.

Metals demand

The demand for aluminium is slightly higher in the steel can system than in the aluminium can system. The reason is that the aluminium lid on the steel can is oxidised in the steel recycling process. The energy in the aluminium lid is utilised, but the material is lost. The aluminium in the aluminium cans, on the other hand, is remelted into secondary aluminium which in the base case replaces 100% primary aluminium.

Iron and tin are mainly used in the tinsteel cans. Manganese is an alloy metal in aluminium cans.

Global warming etc.

In the base case scenario, the refillable PET bottle contributes least to the potential global warming, acidification and nutrification. The differences are large: our results indicate that the GWP of the competing packagings is more than three times the GWP of the refillable PET bottle. For the acidification and nutrification categories, the other packagings contribute more than twice as much as the refillable PET bottles.

POCP

The results indicate that the refillable PET bottle contributes slightly more to the potential photochemical formation of ozone (POCP) than the aluminium can. However, the difference between the systems is not significant due to the large uncertainty connected to the POCP of unspecified VOC emissions.

Table 13.4

Comparison of net total potential environmental impacts for 50 cl soft-drink packaging systems in the base case. The table presents characterisation results. Functional unit: packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Unit	Refillable PET bottle	Disposable PET bottle	Aluminium can	Steel can
Global warming	kg CO_2-eq	6.1E+00	2.0E+01	2.1E+01	2.6E+01
Photochemical ozone formation	kg C_2H_4-eq	1.1E-02	6.4E-02	8.4E-03	1.1E-02
Acidification	kg SO_2-eq	4.4E-02	2.2E-01	9.9E-02	1.2E-01
Nutrient enrichment	kg NO_3-eq	4.3E-02	1.4E-01	1.0E-01	1.2E-01

Table 13.5

Normalisation of net total potential environmental impacts for 50 cl soft-drink packaging systems in the base case. The unit of the normalised impacts is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Normalisation reference	Refillable PET bottle [PE/FU]	Disposable PET bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Global warming	8700	7.0E-04	2.3E-03	2.4E-03	3.0E-03
Photochemical ozone formation	20	5.6E-04	3.2E-03	4.2E-04	5.3E-04
Acidification	124	3.6E-04	1.8E-03	8.0E-04	9.8E-04
Nutrient enrichment	298	1.5E-04	4.7E-04	3.4E-04	4.1E-04

Table 13.6

Weighting of net total potential environmental impacts for 50 cl soft-drink packaging systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refer to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Weighting factor	Refillable PET bottle [PET/FU]	Disposable PET bottle [PET/FU]	Aluminium can [PET/FU]	Steel can [PET/FU]
Global warming	1.2	9.1E-04	3.0E-03	3.2E-03	4.0E-03
Photochemical ozone formation	1.2	6.8E-04	3.8E-03	5.0E-04	6.4E-04
Acidification	1.3	4.6E-04	2.4E-03	1.0E-03	1.3E-03
Nutrient enrichment	1.3	1.8E-04	5.7E-04	4.0E-04	4.9E-04

Waste

In the base case scenario, the PET bottles generate less waste than the cans. This is true for all waste categories. The refillable PET bottle generates much less bulk waste, and slag & ashes than the competing containers. Both PET bottles generate much less hazardous waste than the steel and aluminium cans.

Table 13.7

Normalisation of waste flows from 50 cl soft-drink packaging systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drinks. The unit of the normalisation reference is kg per person and year.

Waste category	Normalisation Reference	Refillable PET bottle [PE/FU]	Disposable PET bottle [PE/FU]	Aluminium can [PE/FU]	Steel can [PE/FU]
Bulk waste	1350	8.6E-04	2.5E-03	3.9E-03	6.8E-03
Hazardous waste	20.7	2.3E-03	2.4E-03	1.6E-02	2.9E-02
Slag and ashes	320	1.1E-04	5.8E-04	2.6E-03	1.3E-03

Table 13.8

Weighting of waste flows from 50 cl soft-drink packaging systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refer to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Waste category	Weighting factor	Refillable PET bottle [PET/FU]	Disposable PET bottle [PET/FU]	Aluminium can [PET/FU]	Steel can [PET/FU]
Bulk waste	1.1	9.4E-04	2.8E-03	4.3E-03	7.5E-03
Hazardous waste	1.1	2.6E-03	2.6E-03	1.8E-02	3.2E-02
Slag and ashes	1.1	1.2E-04	6.4E-04	2.9E-03	1.4E-03

13.3 Sensitivity analyses

As stated in the previous chapters, the sensitivity analyses take into account emissions of CO_2, SO_2, NO_X and VOC. The various sensitivity analyses are described in section 2.13. The results are presented in the interpretation sections in chapters 5-8 (see, *e.g.*, Table 5.14) and - in more detail - in section 5.2.4 in Technical reports 3-6.

Electricity production

As discussed in previous chapters, the electricity production is important for the results of this LCA. In the base case scenario, electricity production is responsible for more than half of the net total CO_2 emissions and nearly half of the SO_2 and NO_X emissions from the 50 cl aluminium and steel can systems. If the marginal electricity production technology is nuclear power - or another non-fuel technology - electricity production would contribute little to these emissions (see, *e.g.*, Brännström-Norberg *et al.* 1996, see also section 2.7.3).

Using the scenario with fragmented electricity markets, the emissions of SO_2 from the aluminium system are reduced by approximately 20% for the aluminium can system. Emissions of CO_2 and NO_X from this system are reduced by approximately 10% (see chapter 5). The effects on the emissions caused by the steel can system are slightly smaller if calculated in percentages of the net total emissions (see chapter 6).

However, if part of the electricity is based on natural gas, the emissions of the PET bottles are also reduced. In the scenario with fragmented markets, the SO_2 emissions caused by the refillable PET bottle system are reduced by 14%. The CO_2 and NO_x emissions are reduced by approximately 10% (see chapter 7).

Packaging weight

As discussed in section 10.3, the weight of the primary packaging has limited effect on the LCA results. This is true also for the PET bottles.

Recycling rates

The results for the refillable PET bottle are very sensitive to changes in collection rates. If the collection rate of refillable PET bottles is 90% rather than 98.5%, the SO_2 emissions would be more than doubled. The emissions of CO_2, NO_x and VOC would be increased by 50-70% (see chapter 7).

If the collection of 50 cl aluminium cans is 98.5% instead of 90%, the emissions of CO_2, SO_2 and NO_x are reduced by approximately 15-25%. However, the VOC emissions are not significantly affected.

Discarded PET bottles

A change in the share of discarded PET bottles at the brewery is likely to have somewhat smaller effects than a change in the collection rate (cf. section 10.3).

Use of recycled material

The share of secondary aluminium in the aluminium cans and the lids of steel cans has no effect on the LCA results (see section 10.3). However, use of recycled material in the production of PET bottles would have significant effects, in particular on the results of the disposable PET bottle.

Allocation

The assumption that recycled PET from the packaging systems replaces 50% virgin material and 50% recycled material from other systems is important, in particular for the disposable PET bottle. If we assume that recycled PET will replace 100% virgin material, the VOC emissions of the disposable PET bottle are reduced by 65%. The NO_x and SO_2 emissions are reduced by 35 % and the CO_2 emissions by 20% (see chapter 8). For the refillable PET bottle, the effects are somewhat smaller but the potential photochemical ozone formation would still be reduced by nearly 30%. The acidification potential would be reduced by approximately 15% for the refillable PET bottle (see Technical report 5).

The discussion in the previous paragraph is also valid if recycled PET from the packaging system only displaces recycled material from other systems. However, in this case, the emissions and impacts will be increased instead of reduced. For example, the VOC emissions of the disposable PET bottle would be increased by 65%, if only recycled material was displaced.

The assumption that recycled aluminium and tinsteel from the packaging systems will replace 100% virgin material is also fairly important. If we assume that recycled tinsteel will replace 50% virgin material and 50% steel scrap from other systems, the CO_2, SO_2, NO_x and VOC emissions of the steel can system are increased by approximately 10-25%. The assumption might also be important for the aluminium can system.

Transport data

The distribution is fairly important for the total LCA results. If light trucks are used, rather than the medium and heavy trucks indicated by our data, the NO_X emissions from the refillable PET bottle system are increased by 30%. Emissions of CO_2 and VOC are increased by nearly 10-20%. The effects on SO_2 emissions are relatively small. The effects on emissions from the aluminium and steel can systems are also relatively small.

Omissions

The analysis of the refillable PET bottle system does not include the production of NaOH used in the washing and filling processes. Furthermore, the retailer and the private transport home from the retailer are not included in the LCA. Including the production of NaOH in the systems would increase the energy demand of the refillable PET bottle by approximately 6%. Hence, the total emissions of CO_2, SO_2, NO_X and VOC would be slightly increased. The retailer and the private transport have a minor effect on the LCA results (see chapter 7).

The packaging systems also have a large number of other non-elementary inflows, *i.e.*, materials that are not traced back to the boundary between technosphere and nature. The energy demand of the sensitivity analyses presented in Technical reports 1-6 indicates that these omissions do not have a significant impact on the total CO_2, SO_2, NO_X and VOC emissions from the systems.

13.4 Conclusions

There are large differences between the environmental impacts of the refillable PET bottle and the other 50 cl soft-drink packagings. However, the uncertainties are also large. One important uncertainty concerns what material will be replaced by recycled plastics from the PET bottle systems. Another is the collection rate for refillable PET bottles. There are also large uncertainties in the environmental impacts of base-load marginal electricity production.

Final energy

The demand for electricity and fossil fuel at final use is significantly lower for the refillable PET bottle than for disposable PET bottles. The reason is that washing and refilling of bottles demand less energy than material recycling and production of new PET bottles.

The electricity demand is significantly lower for the refillable PET bottle than for steel and aluminium cans.

Primary fuels

In the base case, the demand for primary fossil fuel is much lower in the refillable PET bottle system than in the other systems. The difference in the demand for oil and natural gas is fairly significant. This is a small difference compared to the previous study, where there was no significant difference between the total demand for fossil fuel in the refillable PET and the aluminium can systems.

Metals

In the base case scenario, the demand for primary aluminium is slightly lower for the aluminium can than for the steel can. This confirms the results of the previous study. However, the difference is only significant at high recycling rates and under the assumption that the recycled aluminium from the packaging system replaces 100% primary aluminium.

The iron and tin demand is significantly higher for the steel can than for other packagings. The manganese demand is higher in the aluminium can system.

Global warming

In the base case, the global warming potential (GWP) is 3-4 times lower for the refillable PET bottle than for the other packagings. Despite the important uncertainties in collection rate, electricity production etc., this difference is significant. This conclusions differ from the previous study, where there was no significant difference between the refillable PET bottle and the aluminium can.

The GWP is slightly lower for the disposable PET bottle than for the steel and aluminium cans in the base case. However, due to the large uncertainties in the material replaced by recycled PET, and in the CO_2 emissions from the marginal electricity production, this difference is not significant.

The relatively small difference in the GWP of steel and aluminium cans is fairly significant (see section 11.4).

Table 13.9

Ranking order of the 50 cl soft-drink packaging systems. This ranking is estimated based on the base case results, the dominance analysis, and the uncertainties investigated in the sensitivity analyses and in the assessments of data quality data gaps.

Environmental impacts	Refillable PET bottle	Disposable PET bottle	Aluminium can	Steel can
Global warming	1	2-4	2-3	3-4
Photochemical ozone	1-3	4	1-2	2-3
Acidification	1-2	4	1-2	3
Nutrient enrichment	1-2	2-4	1-3	3-4

POCP

The potential photochemical ozone formation (POCP) is 25% lower for the aluminium can than for the refillable PET bottle in the base case. However, there is an important uncertainty concerning the material replaced by recycled PET. Another important uncertainty concerns the POCP of unspecified VOC and hydrocarbon emissions (see section 10.4). Due to these uncertainties, the difference between the refillable PET bottle and the aluminium can is not significant. The difference in POCP between the refillable PET bottle and the steel can is small and not significant. This confirms the conclusions of the previous study.

The POCP is approximately six times higher for the disposable PET bottle than for the other packagings in the base case. This difference is significant. The relatively small difference between steel and aluminium cans is also fairly significant (see section 11.4). This an adjustment compared to the conclusions in the previous study.

Acidification

The acidification potential for the refillable PET bottle is less than half the corresponding figure for the aluminium can in the base case. However, if the marginal electricity in the aluminium can system is mainly based on natural gas - or non-fuel technology - the difference in acidification between these packaging systems is relatively small. Furthermore, the emissions from the refillable PET system are very sensitive to uncertainties in the collection rate (see section 13.3). From this we conclude that the difference between the refillable bottle and the aluminium can is significant only if the marginal electricity production to a large share is based on fossil fuel other than natural gas. This is an adjustment compared to the previous study, where the acidification potential was slightly (and insignificantly) lower for the aluminium can than for the 50 cl refillable PET bottle.

In the base case, the acidification potential for the steel can is nearly three times as high as for the refillable PET bottle. Despite the large uncertainty in SO_2 and NO_X emissions from the marginal electricity production, and the important uncertainty in the collection rate, we estimate this difference to be fairly significant. This is a small adjustment compared to the previous study.

The acidification potential is five times higher for the disposable PET bottle than for the refillable bottle in the base case. This difference is significant, and more conclusive than in the previous study.

The relatively small difference between steel and aluminium cans is fairly significant (see section 11.4). The acidification of both cans is significantly lower than the acidification of the disposable PET bottle. This is different from the previous study, where the difference between steel cans and disposable PET bottles was estimated not to be significant.

Nutrification

The nutrient enrichment potential for the refillable PET bottle is less than half the corresponding figure for the aluminium can in the base case. However, if the marginal electricity technology in the aluminium can system is mainly nuclear power, the difference in nutrification between these packaging systems is small. Hence, the difference between the refillable bottle and the aluminium can is significant only if the marginal electricity production to a large share is based on the combustion of fuel. This is still an adjustment compared to the previous study, where the acidification potential was slightly (and insignificantly) lower for the aluminium can than for the 50 cl refillable PET bottle.

In the base case, the nutrient enrichment potential is approximately three times higher for the steel can and the disposable PET bottle than for the refillable bottle. We estimate that these differences are significant. This is a change compared to the previous study, where the difference between refillable PET bottles and steel cans was estimated not to be significant.

The relatively small difference between steel and aluminium cans is fairly significant (see section 11.4). The difference between the disposable PET bottle and the 50 cl soft-drink cans is not significant, however, mainly due to the large uncertainty concerning what material is replaced by recycled PET. This is different from the previous study, where the nutrification potential of the 50 cl aluminim can was estimated to be significantly lower than the nutrification potential of the disposable PET bottles.

Waste

The PET bottles generate less waste than the can systems for all waste categories. This confirms the results from the previous study.

It should be added that if the marginal electricity is mainly nuclear power, the refillable PET bottle generates less radioactive waste than the disposable bottle. The reason is that the electricity demand is significantly lower for the refillable bottle than for the disposable bottle. For the same reason, the amount of radioactive waste is significantly lower for both the PET bottles than for the aluminium and steel can systems (see Table 13.1).

14 Comparison of 150 cl PET bottles

14.1 Introduction

Systems compared

The LCAs summarised above include the assessment of systems with two different 150 cl PET bottles:

- refillable bottles, and
- disposable bottles.

Limitations

This chapter presents an environmental comparison of the two packaging systems. Like in the previous chapters, the comparison is limited to the environmental impacts covered by the LCAs. This means that, *e.g.*, work environment and health impacts from use and misuse of the packaging are not included in the comparison.

14.2 The base case

Energy at final use

Table 11.1 presents the final use of fuel and electricity, as opposed to the demand for primary energy. This means that, *e.g.*, the fossil fuel demand does not include fossil fuel used for electricity production.

The results indicate that the electricity demand is the same for the two systems, but that the fossil fuel demand at final use is nearly double for the steel can compared to the aluminium can. The demand for renewable fuel and other energy carriers is relatively small in both systems.

Table 14.1
Net total energy demand at final use for 150 cl PET bottle systems in the base case. Functional unit: packaging and distribution of 72.3 litres of soft-drink.

Energy demand	Unit	Refillable bottle	Disposable bottle
Electricity	kWh	2.39E+00	3.09E+00
Fossil fuel	MJ	4.32E+01	1.56E+02
Renewable fuel	MJ	3.82E-01	7.31E-01
Heat etc.	MJ	-1.59E-01	-3.07E-01

Table 14.2
Normalisation of net total depletion of selected resources for 150 cl PET bottle systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drink. The unit of the normalisation reference is kg per person and year.

Resource	Normalisation Reference	Refillable bottle [PE/FU]	Disposable bottle [PE/FU]
Oil	590	1.2E-03	3.2E-03
Coal	931	1.5E-03	2.4E-03
Brown coal	250	7.0E-05	8.8E-05
Natural gas	310	7.6E-04	2.4E-03
Aluminium	3.4	6.9E-06	3.5E-05
Iron	100	5.0E-08	2.3E-07
Manganese	1.8	4.5E-06	3.3E-05
Tin	0.04	0	0

Table 14.3
Selected weighting results for net total resource depletion of 150 cl PET bottle systems in the base case. The unit is person-reserve (PR) per functional unit (FU). The person-reserve is the fraction of the known global reserves per person in the world in 1990 (Hauschild & Wenzel 1998). The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Resource	Weighting factors	Refillable bottle [PR/FU]	Disposable bottle [PR/FU]
Oil	0.023	2.7E-05	7.3E-05
Coal	0.0058	8.7E-06	1.4E-05
Brown coal	0.0026	1.8E-07	2.3E-07
Natural gas	0.016	1.2E-05	3.8E-05
Aluminium	0.0051	3.5E-08	1.8E-07
Iron	0.0085	4.3E-10	2.0E-09
Manganese	0.012	5.4E-08	4.0E-07
Tin	0.037	0	0

Resource demand

The demand for fossil fuel is higher in the disposable PET system than in the refillable system (see Tables 14.2-3). The demand for oil and natural gas is much higher. The main reason is that the PET resin production and the bottle production are much larger in the disposable PET bottle system.

The demand for metals is also higher in the disposable system than in the refillable system. However, the metals demand is low for both systems.

In these respects, our comparison confirms the results of the previous study.

Environmental impacts

Our results indicate that most environmental impacts are higher for the disposable PET bottles than for the refillable bottles in the base case scenario (see Tables 14.4-6). The difference is large for global warming, photochemical ozone formation, acidification, nutrient enrichment.

Global warming etc.

The large difference in potential global warming, acidification and nutrient enrichment is due to the fact that PET resin production and bottle production is much larger in the disposable bottle system. As a consequence, the emissions of CO_2, SO_2 and NO_X are much larger in the disposable bottle system (see section 5.1 in Technical reports 6 and 7).

The difference in photochemical ozone formation is mainly due to the large difference in VOC emissions from PET resin production.

Table 14.4

Comparison of net total potential environmental impacts for 150 cl PET bottle systems in the base case. The table presents characterisation results. Functional unit: packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Unit	Refillable bottle	Disposable bottle
Global warming	kg CO_2-eq	5.1E+00	1.2E+01
Photochemical ozone formation	kg C_2H_4-eq	8.0E-03	3.6E-02
Acidification	kg SO_2-eq	3.4E-02	1.3E-01
Nutrient enrichment	kg NO_3-eq	3.7E-02	8.6E-02

Table 14.5

Normalisation of net total potential environmental impacts for 150 cl PET bottle systems in the base case. The unit of the normalised impacts is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Normalisation reference	Refillable bottle [PE/FU]	Disposable bottle [PE/FU]
Global warming	8700	5.8E-04	1.3E-03
Photochemical ozone formation	20	4.0E-04	1.8E-03
Acidification	124	2.7E-04	1.0E-03
Nutrient enrichment	298	1.2E-04	2.9E-04

Table 14.6

Weighting of net total potential environmental impacts for 150 cl PET bottle systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refers to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Environmental impacts	Weighting factor	Refillable bottle [PET/FU]	Disposable bottle [PET/FU]
Global warming	1.2	7.6E-04	1.7E-03
Photochemical ozone formation	1.2	4.8E-04	2.1E-03
Acidification	1.3	3.6E-04	1.3E-03
Nutrient enrichment	1.3	1.5E-04	3.4E-04

Waste

The waste flows from the disposable PET systems are larger than the flows from the refillable system (see Tables 14.7-8). However, all waste flows from the PET systems are relatively small (see section 13.2).

Table 14.7
Normalisation of waste flows from 150 cl PET bottle systems in the base case. The unit of the normalised resource depletion is person equivalents (PE) per functional unit (FU). The person equivalents refer to an average person in the world or in Denmark in 1990. The functional unit is the packaging and distribution of 72.3 litres of soft drink. The unit of the normalisation reference is kg per person and year.

Waste category	Normalisation Reference	Refillable bottle [PE/FU]	Disposable bottle [PE/FU]
Bulk waste	1350	6.7E-04	1.3E-03
Hazardous waste	20.7	2.2E-03	1.3E-03
Slag and ashes	320	9.1E-05	3.3E-04

Table 14.8
Weighting of waste flows from 150 cl PET bottle systems in the base case. The unit of the normalised impacts is person equivalents at target level (PET) per functional unit (FU). The PET refers to an average person in a future world or in Denmark when the target levels of the year 2000 have been reached. The functional unit is the packaging and distribution of 72.3 litres of soft drink.

Waste category	Weighting factor	Refillable bottle [PET/FU]	Disposable bottle [PET/FU]
Bulk waste	1.1	7.4E-04	1.4E-03
Hazardous waste	1.1	2.4E-03	1.4E-03
Slag and ashes	1.1	1.0E-04	3.6E-04

14.3 Sensitivity analyses

As stated in the previous chapters, the sensitivity analyses take into account emissions of CO_2, SO_2, NO_X and VOC. The various sensitivity analyses are described in section 2.13. The results are presented in the interpretation sections in chapters 7 and 8 (see, *e.g.*, Table 7.14) and - in more detail - in section 5.2.4 in Technical reports 5 and 6.

Electricity production

As discussed in previous chapters, the electricity production is important for the results of this LCA, although slightly less important for the PET bottles than for the aluminium and steel cans. Using the scenario with fragmented electricity markets, the SO_2 emissions caused by the refillable 150 cl PET bottle are reduced by approximately 15%. The CO_2 and NO_X emissions are reduced by approximately 10%.

Packaging weight

As discussed in section 10.3, the weight of the primary packaging has a limited effect on the LCA results. This is true also for PET bottles.

Recycling rates

As indicated in the previous chapter, the results for the refillable PET bottle are very sensitive to changes in collection rates. If the collection rate of refillable 150 cl PET bottles is 90% rather than 98.5%, the SO_2 emissions would be more than doubled. The emissions of CO_2, NO_x and VOC would be approximately 50-70% larger than in the base case.

Discarded PET bottles

A change in the share of discarded PET bottles at the brewery is likely to have smaller effects than a change in the collection rate (cf. section 10.3).

Use of recycled material

The share of secondary aluminium in the aluminium cans and the lids of steel cans has no effect on the LCA results (see section 10.3). However, the use of recycled material in the production of PET bottles would have significant effects, in particular on the results of the disposable PET bottle.

Allocation

The assumption that recycled PET from the packaging systems replaces 50% virgin material and 50% recycled material from other systems is important, in particular for the disposable PET bottle. If we assume that recycled PET will replace 100% virgin material, the VOC emissions of the disposable PET bottle are reduced by more than half. The NO_x and SO_2 emissions are reduced by 35 % and the CO_2 emissions by 20% (see chapter 8). For the refillable PET bottle, the effects are somewhat smaller but the potential photochemical ozone formation would still be reduced by nearly 30%. The acidification potential would be reduced by approximately 15% for the refillable PET bottle (see Technical report 5). If recycled PET from the packaging systems displaces 100% recycled material, the emissions and impacts are increased by the same amounts.

Transport data

The distribution is fairly important for the total LCA results. However, the results on refillable and disposable PET bottle systems would be fairly equally affected by a change in the transport data.

Omissions

The analysis of the PET bottle systems does not include the production of NaOH used in the washing of refillable bottles, nor the retailer and the private transport home from the retailer. Including the production of NaOH in the systems would increase the energy demand of the refillable PET bottle by approximately 8%. Hence, the total emissions of CO_2, SO_2, NO_x and VOC would be somewhat increased. The retailer and the private transport has no significant effect on the LCA results (see chapter 7).

The PET bottle systems also have a large number of other non-elementary inflows, *i.e.*, materials that are not traced back to the boundary between technosphere and nature. The energy demand of the sensitivity analyses presented in Technical reports 1-6 indicates that these omissions do not have a significant impact on the total CO_2, SO_2, NO_x and VOC emissions from the systems.

14.4 Conclusions

The production of PET resins and PET bottles demands more energy than the washing of refillable PET bottles. This is true also when the production of the NaOH used in the washing process is included in the analysis.

More PET is required to produce the heavier refillable bottle than the disposable PET bottle. But the difference in the amount of PET required for producing the bottle is not so important if the bottle is used many times.

Our calculations indicate that the electricity and fuel demand are significantly lower for refillable bottles than for disposable PET bottles if the collection rate is high. The difference in total fossil fuel demand is large.

The potential global warming, acidification, photochemical ozone formation and nutrification are also significantly lower for the refillable bottle than for the disposable PET bottle (see Table 14.9). The difference is likely to be large (see, *e.g.*, Table 14.4). This confirms the conclusions from the previous study.

Our results indicate that the waste flows are smaller for the refillable bottle than for the disposable PET bottle. This is true for all waste categories and confirms the results from the previous study.

Table 14.9
Ranking order of the 150 cl PET bottles. This ranking is estimated based on the base case results, the dominance analysis, and the uncertainties investigated in the sensitivity analyses and in the assessments of data quality data gaps.

Environmental impacts	Refillable PET bottle	Disposable PET bottle
Global warming	1	2
Photochemical ozone formation	1	2
Acidification	1	2
Nutrient enrichment	1	2

15 General conclusions

15.1 Comparisons between systems

Limitations

This section presents a summary of the most important methodological aspects and the conclusions that can be drawn regarding the comparisons made between the packaging systems.

Purpose

As stated in the goal of the study (section 2.1), this is an updated comparison of existing and alternative packaging systems for beer and carbonated soft drinks that are filled and sold in Denmark. The purpose of the study is to improve the basis for possible decision-making on these systems.

Function / Functional unit

The function of the packaging systems is to facilitate the distribution of beer and/or carbonated soft drinks from the breweries via retailers to the consumers. In the assessment of the individual systems, the functional unit is packaging and distribution of 1000 litres of beverage.

When the different systems are compared, the functional unit is based on the average annual consumption of the relevant beverage for one person in Denmark in 1993: 128.2 litres of beer and 72.3 litres of carbonated soft drinks.

Systems boundaries

The LCA includes not only the packaging systems but also the distribution of beverage. System boundaries are also expanded to include parts of other systems that are affected by recycling in the packaging system, or by waste incineration with energy recovery (see section 2.5).

Marginal data

The ideal data to use in this study represents the technologies actually affected by a decision on the packaging system. For markets where the decision will have a marginal impact - *e.g.*, electricity and bulk material markets - data reflecting the long-term marginal technology were judged to be the most relevant for the purpose of this study (section 2.9). This methodological choice is particularly important for the environmental impacts of electricity production.

Assumptions

The key assumptions are described and discussed in section 2.7. One of the important assumptions made is that consumer behaviour is not affected by the choice between packagings of the same size.

We also assume that all the analysed systems will operate under a return scheme, similar to that presently operating in Denmark for refillable glass bottles. The collection rate for refillable glass bottles is assumed to be 98.5%. Of the disposable bottles and cans, 90% is assumed to be collected for recycling of the materials. Sensitivity analyses were made based on other collection rates.

In the base case scenario, the long-term marginal technology for electricity production is assumed to be coal condensing power. Other energy scenarios were used in the sensitivity analysis.

All broken glass, aluminium scrap and steel scrap available for recycling are assumed to be recycled. This means that, *e.g.*, recycled glass, aluminium and steel from the packaging system are assumed to replace 100% virgin raw materials. Recycled PET is assumed to displace 50% virgin raw materials and 50% recycled PET from other systems.

Impact categories

The impact assessment method used in this study is the EDIP method. It takes into account potential global warming, ozone depletion, acidification, nutrient enrichment, human toxicity (caused by exposure via air, water and soil) and ecotoxicity (acute and chronic toxicity in water, and chronic terrestrial toxicity). It also takes resource depletion and generation of waste into account. The EDIP method does not take into account land-use related impacts and noise. Work environment and health impacts from use and misuse of the packaging are not included in this particular study (see also section 2.11).

Uncertainties

Large uncertainties are involved in a broad systems analysis such as this. The importance of various uncertainties is addressed in sensitivity analyses (sections 10.3, 11.3, 12.4, 13.3 and 14.3) and in assessments of data quality and data gaps (*e.g.*, sections 5.3-5.4 in Technical reports 1-6). We estimate that the most important uncertainties concern:

- the electricity production - more specifically the environmental impacts of the long-term marginal technology for base-load electricity production,
- the market for recycled materials - in particular the effects of an increased flow of secondary PET from the packaging system,
- the recycling rates, and
- the transport data.

Data quality

As stated above, we should ideally use data reflecting the technologies actually affected by a decision. We used marginal data when possible for the parts of the systems where a decision on Danish beverage packagings have a marginal effect. We were not able to obtain marginal data for all relevant processes, but we believe we used marginal data where it was most important, *e.g.* for electricity production, waste management and steel recycling.

The quality of the data used in this study varies. Site specific data were collected for glass production, but average data were used for primary production of primary aluminium, steel and PET. This is due to the fact that it is fairly certain at which site the glass will be produced, but it is uncertain where the other materials will be produced. This introduces an additional uncertainty in the results, but we estimate this uncertainty to be smaller than the uncertainties discussed above.

Omissions

The packaging systems have a large number of non-elementary inflows, *i.e.*, materials that are not traced back to the boundary between technosphere and nature. Furthermore, the retailer and the private transport home from the retailer are not included in the LCA. The sensitivity analyses presented in Technical reports 1-6 indicate that these omissions are not important for the total LCA results.

Ranking procedure

Packagings with similar content and size were compared in chapters 10-14. The comparison included energy demand at final use, demand for natural resources, potential global warming, acidification, photochemical ozone formation and nutrient enrichment, and three different waste categories. We also compared potential toxicity and ecotoxicity impacts. For these impacts the comparison is not reported, because we found no significant differences between the systems. This is not because the different systems have similar toxicity impacts, but because the uncertainties are very large (see section 2.11).

For the potential global warming, acidification, photochemical ozone formation and nutrient enrichment a formal ranking is presented in tables (see, *e.g.*, section 10.4). This ranking shows what differences we consider to be significant. The assessment of the significance of the differences is based on the sensitivity analyses and the assessments of data quality and data gaps performed in this study. This means that, *e.g.*, all the uncertainties discussed above are taken into account. However, it should be stressed that the assessment and the ranking is based on Danish conditions.

The differences between beer and soft-drink packagings are fairly small. This means the same conclusions hold for 33 cl beer containers and for 33 cl soft-drink packagings.

Refillable vs. disposable glass bottles

The energy demand, potential global warming, acidification, nutrification and photochemical ozone formation, are all significantly lower for the refillable glass bottles than for the disposable glass bottles of the same size (see Table 15.1). The reason is that recycling of glass demands more fuel and electricity than washing and filling of refillable bottles.

Table 15.1
Environmental ranking order of existing or alternative systems with 33 cl packagings for beverages that are filled and sold in Denmark. See also chapters 10 and 12.

Environmental impacts	Refillable glass bottle	Disposable glass bottle	Aluminium can	Steel can
Global warming	1-2	2-4	1-3	3-4
Photochemical ozone	1-2	2-4	1-3	3-4
Acidification	1-2	3-4	1-2	3-4
Nutrient enrichment	1-2	3-4	1-2	3-4

Refillable glass vs. aluminium

The differences in potential global warming, photochemical ozone formation, acidification, and nutrient enrichment between the refillable glass bottle and the 33 cl aluminium can are not significant. The main reason for this is the large uncertainties in the environmental impacts of the long-term marginal production of base-load electricity. The global warming potential is significantly lower for the refillable glass bottle than for the aluminium can if the marginal electricity to a large extent is based on fossil fuel. The acidification potential is significantly lower for the refillable bottle than for the aluminium can if the marginal electricity to a large extent is based on fossil fuel other than natural gas. And the nutrification potential is significantly lower for the refillable bottle than for the aluminium can if the marginal electricity to a large extent is based on the combustion of any fuel (see also section 10.4).

The electricity demand is significantly lower for the refillable glass bottle than for the aluminium can. The demand for fossil fuel as final energy - process energy and vehicle propellant - is lower for the aluminium can, but if the marginal electricity production is based on fossil fuel, the total demand for fossil fuel is significantly higher for the aluminium can than for the refillable glass bottle.

Aluminium vs. steel

Aluminium cans are likely to be environmental superior to steel cans with aluminium lids, as long as the aluminium lid is not separately recycled. The difference between the environmental impacts of the aluminium and steel cans is relatively small - approximately 20% - but it is significant when the collection rate is in the order of 90%, if recycled aluminium and steel replace 100% primary metals. This conclusion is valid for the potential global warming, acidification, nutrification and photochemical ozone formation.

The total energy demand is also significantly lower for the aluminium can than for the steel can. The difference in electricity demand is quite small and not significant, but there is a significant difference in fossil fuel demand.

These relations are valid for 50 cl cans as well as for 33 cl cans and for beer as well as for soft-drink cans. The main reason for the differences is that the aluminium in the aluminium lid is lost in the steel recycling process. As a result, the demand for primary aluminium is higher in the steel can system than in the aluminium can system. In addition, the steel can system demands tinsteel (see also section 11.4).

Refillable vs. disposable PET bottles

The energy demand, potential global warming, acidification, nutrification and photochemical ozone formation, are significantly lower for the refillable PET bottles than for the disposable PET bottles of the same size (see Table 15.2). The conclusion is valid for 150 cl bottles as well as for 50 cl bottles. The reason is that recycling of PET demands more fuel and electricity than washing and filling of refillable bottles.

Table 15.2
Environmental ranking order of existing or alternative systems with 50 cl packagings for beverages that are filled and sold in Denmark. See also chapter 13.

Environmental impacts	Refillable PET bottle	Disposable PET bottle	Aluminium can	Steel can
Global warming	1	2-4	2-3	3-4
Photochemical ozone	1-3	4	1-2	2-3
Acidification	1-2	4	1-2	3
Nutrient enrichment	1-2	2-4	1-3	3-4

Refillable PET vs aluminium

Our results indicate that the potential global warming, acidification, and nutrification are much lower for the 50 cl refillable PET bottle than for the other 50 cl soft-drink packagings, including the aluminium can. However, the uncertainties in these results are large. One important uncertainty concerns the environmental impacts of the long-term base-load marginal electricity production. Another important uncertainty concerns what material will be replaced by recycled plastics from the PET bottle systems. The effects of any error in the collection rate for refillable PET bottles are also large. As a result of these uncertainties, we only consider the difference in global warming potential to be significant. However, the acidification potential is significantly lower for the refillable bottle than for the aluminium can if the marginal electricity to a large extent is based on fossil fuel other than natural gas. And the nutrification potential is significantly lower for the refillable bottle than for the aluminium can if the marginal electricity to a large extent is based on any fuel (see also section 13.4).

The electricity demand is significantly lower for the 50 cl refillable PET bottle than for the 50 cl aluminium can. The difference in fossil fuel demand for process energy and vehicle propellant is small and not significant. But if the marginal electricity production is based on fossil fuel, the total demand for fossil fuel is significantly lower for the refillable PET bottle than for the aluminium can.

15.2 Further improvements in the systems

Many environmental improvements can be made within the systems. The purpose of this study was not to identify improvement options for the systems investigated. However, we still present two potential improvement options in the packaging systems. These improvements would have significant effects on the environmental impacts of the packaging systems. It should be noted that this discussion is mainly based on the LCA results. It does not account for effects on the work environment. Nor is it based on a deep analysis of the economic and technical feasibility of the improvement options.

The LCA results for the steel cans would probably be significantly lower if the aluminium in collected steel cans was used for the production of secondary aluminium. The collected steel cans should be shredded into small pieces, and the aluminium separated from the tinsteel. The aluminium and the steel should be separately recycled. If necessary, the tinsteel can be detinned. However, an environmental assessment of the detinning process is recommended before such a decision is taken.

The energy demand at the washing and filling is an important part of the packaging systems for refillable glass bottles. The large difference between the washing and filling of different refillable bottles indicates that significant improvements can be made in energy efficiency. Improvements in energy efficiency are often economically profitable.

15.3 Comparison to the previous study

An update

As indicated above, this study is an update of a previous study performed in the period 1992 to 1996. A rather detailed analysis of the differences between the previous study and this update study is presented in Annex A. The most important changes compared to the previous study are:

- data are improved and updated,
- conditions which have changed since the previous study are taken into account,
- the international standards ISO 14040 and ISO FDIS 14041 are used, and
- also the most recent developments within the Danish project on Environmental Design of Industrial Products (EDIP) are taken into account.

Updated data

Updated and improved data have been used for all or almost all parts of the systems investigated. The most important updates in the data set includes the use of new and improved data for the distribution, for the production of the main materials (glass, aluminium, steel, PET and corrugated board). Improved data on the weight of the corrugated trays and cardboard boxes are also important for the total LCA results. Furthermore, we have taken into account the fact that breweries and soft-drink producers now use natural gas rather than oil for washing and filling processes.

Systems boundaries

As indicated above, the LCA includes not only the packaging systems but also the distribution of beverage. System boundaries are also expanded to include parts of other systems that are affected by recycling in the packaging system, or by waste incineration with energy recovery. This is different from the previous study.

Marginal data

We used marginal data when possible for the parts of the systems where a decision on Danish beverage packagings have a marginal effect. This is an important difference compared to the previous study.

Interpretation

The conclusions of this project are based on a systematic interpretation of the LCA results. This is also an important difference compared to the previous study. The interpretation in this study included dominance analyses, sensitivity analyses and assessments of data gaps and data quality.

15.4 Further improvements in the LCA

Due to the improvements in data quality and LCA methodology, we believe that the result of the updated comparison is a significant improvement in the basis for possible decisions on packaging systems for beer and carbonated soft drinks to be filled and sold in Denmark. However, the assessment performed in this project can be further improved in several aspects. The most important aspects include:

- A refined analysis of the markets for recycled material. In particular, it is important to analyse the market for recycled PET. It may also be important to improve the analysis of the markets for recycled aluminium and steel.
- A refined analysis of the electricity market. A deeper analysis should be performed to identify the base-load marginal electricity production.
- Improved data quality for emissions of heavy metals. In particular, the data on Sr and Hg emissions should be improved.
- The variability between different breweries in the demand for energy and NaOH should be investigated.
- The composition of the VOC emissions from the NaOH production should be investigated. The uncertainty in the POCP of these emissions is approximately ±25% of the total POCP result for the refillable glass bottle for beer.
- The glass bottle systems should be expanded to include the effects of recycling of tinsteel recovered after incineration of used caps.
- The production of more ancillary materials should be included in the LCA. One example is the NaOH used in the washing and filling of PET bottles. Another is the washing chemicals used in the production of aluminium cans.

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Annex A:

Comparison of the previous and the updated study

Summary

Content of this annex

This annex contains a comparison between the previous study and the updated study. Only changes with significant influence on the total results are discussed in the comparison. Processes that might have been changed but which have only minor significance for the overall results are not mentioned.

Choice of parameters

To simplify the interpretation of the reasons behind the changes between the results of the previous study and the updated study some inventory results have been chosen as indicators for the environmental impacts. The indicators has been chosen on basis of the results in the previous study and the pilot study (Weidema *et al.*, 1997). According to these, the main contributors to the following environmental impacts are:

- Global warming: carbon dioxide (CO_2)
- Acidification: sulphur oxide and nitrogen oxides (SO_2 and NO_X)
- Eutrophication: nitrogen oxides (NO_X)
- Photochemical ozone creation: volatile organic compounds (VOC)

Hence, the emissions of CO_2, SO_2, NO_X and VOC caused by the packaging systems are used as indicators in this comparison.

The overall results of the comparison are shown in the table below. In this table, the total emissions of CO_2, SO_2, NO_X and VOC in the previous and updated study for 33 cl refillable glass bottles are shown per 1000 litres of beer. The emissions are shown as net amounts (*i.e.*, the total contribution minus the avoided emissions). The difference is shown as a increase (+) or reduction (-) of the net emissions recorded in the previous study.

Table A.1
Total emissions of CO_2, SO_2, NO_X and VOC from the previous and updated study. Functional unit: packaging and distribution of 1000 litres of beverage. The results are rounded.

	CO_2	SO_2	NO_x	VOC
Refillable glass bottles (represented by 33 cl green glass bottles for beer):				
Previous study	220 kg	1380 g	1560 g	600 g
Updated study	160 kg	250 g	660 g	170 g
Difference in %	-25%	-82 %	-57%	-72%
Disposable glass bottles (represented by 33 cl green glass bottles for beer):				
Previous study	400 kg	2380 g	1840 g	600 g
Updated study	340 kg	950 g	1810 g	260 g
Difference in %	-15%	-60%	-2%	-56%
Aluminium cans (represented by 33 cl cans):				
Previous study	110 kg	1160 g	430 g	480 g
Updated study	320 kg	780 g	1220 g	280 g
Difference in %	+190%	-33%	+180%	-42%
Steel cans (represented by 33 cl cans):				
Previous study	380 kg	3010 g	1220 g	830 g
Updated study	380 kg	1020 g	1460 g	270 g
Difference in %	0%	-66%	+20%	-68%
Refillable PET bottles (represented by 150 cl bottles):				
Previous study	96 kg	760 g	440 g	230 g
Updated study	65 kg	190 g	370 g	190 g
Difference in %	-33%	-75%	-16%	-17%
Disposable PET bottles (represented by 150 cl bottles):				
Previous study	250 kg	1490 g	1020 g	930 g
Updated study	150 kg	1010 g	870 g	810 g
Difference in %	-40%	-60%	-14%	-13%

Refillable glass bottles

The main differences for the refillable glass bottles are caused by:

- New data for washing and filling the bottles at the breweries
- New data on fuel consumption for the distribution (and emission factors per ton-km contribution to lower emissions), although this is partly offset by the fact that the updated study includes the weight of the beverage during the distribution. This is also true for the other systems, but there the reduced fuel consumption is more than offset by the inclusion of beverage distribution.

Disposable glass bottles

The main differences for the disposable glass bottles are caused by:

- New data for washing and filling the bottles at the breweries
- Reduction of the weight of the cardboard trays (/boxes) (secondary packaging) and new data for cardboard production
- Change in the scenario for which energy sources that are substituted by the energy produced at the waste incineration plants

Furthermore, the change of bottle top from HDPE to tin-plate has significance for the clear glass bottles for soft drink.

Aluminium cans

The main differences for the aluminium cans are caused by:

- Change of energy scenario for the aluminium production and recycling (in the previous study: hydro-power; in the update: coal condensing plants)
- Inclusion of the production of manganese (alloy in the aluminium)
- Inclusion of the production of methyl acrylate and epoxy resins (surface treatment)
- New data for filling the cans at the breweries
- Inclusion of the weight of the beverage during the distribution
- Reduction of the weight of the cardboard trays (/boxes) (secondary packaging) and new data for cardboard production
- Change in the scenario for which energy sources that are substituted by the energy produced at the waste incineration plants

Steel cans

The main differences for the steel cans are caused by the same factors as for the aluminium cans (caused by the aluminium lid at the steel cans) and differences in the data sources and method of modelling the steel production and recycling.

Refillable PET bottles

The main differences for the refillable PET bottles are caused by:

- New data for production of PET and PET bottles
- New data for filling the bottles at the soft drink producers
- Inclusion of the weight of the beverage during the distribution
- Change in the scenario for which energy sources that are substituted by the energy produced at the waste incineration plants

Disposable PET bottles

The main differences for the disposable PET bottles are caused by the same factors as for refillable PET bottles. Furthermore, the results are influenced by changes in:

- The credit for recycling of PET in the updating (*i.e.*, "avoided PET production")
- Reduction of the weight of the cardboard trays (/boxes) (secondary packaging) and new data for cardboard production

A.1 Introduction

Context of this report

This report is part of a life cycle assessment comparing the potential environmental impacts associated with different packaging systems for beer and carbonated soft drinks filled and sold in Denmark.

The study is an update of a previous study with the same goal where twelve different beverage packaging systems were studied was performed between 1992 and 1996 (Pommer & Wesnaes 1995, Pommer *et al.* 1995a-f, Wesnaes 1995 & 1996), based on data for 1992-1993.

In the updated study more recent data for the packaging systems are used and the methods developed by or required by the International Organisation for Standardisation (ISO 1997a-b) and the Danish EDIP-project (Wenzel *et al.* 1997) have been applied.

Content of this report

This report contains a comparison of selected results between the previous study and the updated study. The inventory results of CO_2, SO_2, NO_x and volatile organic compounds (VOC) are used as indicators in this comparison. Only changes with significant influence on the total results are mentioned. Hence, processes that might have been changed but which have only minor significance for the overall results are *not* mentioned.

Commissioner and practitioner

The study was financed by the Danish Environmental Protection Agency. It was performed by Chalmers Industriteknik (CIT), Göteborg, Sweden and Institute for Product Development (IPU), Lyngby, Denmark.

Compared systems

The comparisons has been performed for:

- 33 cl refillable green glass bottles for beer as a representative for the systems for refillable glass bottles
- 33 cl disposable green glass bottles for beer as a representative for the systems for disposable bottles
- 33 cl aluminium cans as a representative for the aluminium can systems
- 50 cl steel cans as a representative for the steel can systems
- 150 cl refillable PET bottles as a representative for the refillable PET bottle systems
- 150 cl disposable PET bottles as a representative for the disposable PET bottles.

A.2 Choice of parameters for the comparison

The overall goal of this report is to explain the main differences between the results of the previous study (Pommer & Wesnaes 1995, Pommer *et al.* (1995a-f, Wesnaes 1955-1996) and the results of the updated study.

However, it has not been possible to explain all differences between the results of the previous study and the updated study within the budget, hence a number of parameters (CO_2, SO_2, NO_x and volatile organic compounds) have been selected as indicators for the differences.

In this report, only changes with significant influence on the results are mentioned. Hence, processes that might have been changed but which have only minor significance for the overall results are *not* mentioned.

A.2.1 Parameters which are included

To simplify the interpretation of the reasons behind the changes between the results of the previous study and the updated study some inventory results has been chosen as indicators for the environmental impacts.

Basis for the choice of indicators

The indicators has been chosen on the basis of the results of the previous study (Pommer & Wesnaes 1995, Pommer *et al.* (1995a-f, Wesnaes 1955-1996). The results of this have been further analysed in the pilot study (Weidema *et al.*, 1997).

Main contributors

As described in Weidema *et al.* (1997) the main contributors to the following environmental impacts are:

- Global warming: Carbon dioxide (CO_2)
- Photochemical ozone formation: Volatile organic compounds (VOC)
- Acidification: Sulphur oxide and nitrogen oxides (SO_2 and NO_x)
- Eutrophication: Nitrogen oxides (NO_x)

This applies for all the packaging systems. Hence, the inventory results of CO_2, SO_2, NO_x and volatile organic compounds (VOC) are used as indicators in this comparison.

Carbon dioxide

The updated study also has two categories of CO_2, one named "CO_2" (arising from fossil fuels) and a category named "CO_2 (bio)". This CO_2 comes from biological sources (as wood) and has not net contribution to the global warming. Only CO_2 from fossil fuels are included in this comparison, and "CO_2 (bio)" is *not* included in the comparison between the previous study and the updated study.

Sulphur dioxide

In the updated study small amounts of SO_3 and SO_x also occurs in some of the packaging systems (*i.e.* for refillable glass bottles), but in relation to the emissions of SO_2 the amounts are without significance and hence, no attention is paid to SO_3 and SO_x in this comparison.

Nitrogen oxides

In the updated study the category of nitrogen oxides is split into NO_x and NO_2. Hence, both NO_x and NO_2 is included in this comparison.

Volatile organic compounds

In the previous study the category "hydrocarbons" consist of the sum of the inventory categories: "Various unspecified hydrocarbons (HC)" and "Non methane volatile organic compounds (NMVOC)". In the previous study, these two categories dominated the contribution to the photochemical ozone formation significantly, and hence other contributions from *e.g.* methane (CH_4) and carbon monoxide (CO) is not taken into consideration.

The sum of the categories "hydrocarbons" and "NMVOC" from the previous study is compared to the sum of various specified and unspecified hydrocarbons, volatile organic compounds (VOC) and non methane volatile organic compounds (NMVOC) in the updated study. A part of the unspecified VOCs from the previous study have been specified in the updated study.

In the present comparison all these categories will be referred to as "volatile organic compounds (VOC)".

A.2.2 Impact categories which are not included

The changes in the remaining environmental categories have not been analysed for the following reasons:

Toxicity categories

The results of the toxicity categories will all have changed significantly from the previous study, as the calculations of toxicity in the previous study where based on preliminary toxicity factors during the development of the EDIP method. The toxicity categories has been changed slightly, and the toxicity factors has been changed significantly (in some cases with more than a factor 1000), hence it gives no meaning to compare the toxicity results of the previous study and the updated study.

Resources related to the consumption of packaging materials

In general the same materials are used for the packaging systems in the previous and the updated study. Some of the amounts might have been reduced slightly due to the continuos weight reduction of the packaging. A far more significant factor is the allocation method used in respectively the previous and updated study. There is no reason to analyse and explain this for each system.

Resources related to the consumption of fossil fuels

The emission of CO_2 are closely related to the consumption of fossil fuels. Hence the differences between the consumption of fossil fuels in previous study and in the updating will be parallel to the emission of CO_2 and the explanations will be the same, and there are no reason to repeat these. However, there are some changes from consumption of one fossil fuel, *e.g.* oil, into another, *e.g.* natural gas, due to the updated data set and the change of energy scenarios in the updated study, see also the main report.

Waste categories

According to the results from the previous study, the main contributions to the waste categories "slag and ashes" and "radioactive waste" are consumption of energy, hence the emission of CO_2 is used as indicator. Radioactive waste is connected to the energy demand from nuclear power, and ideally this should be zero in the base case of the updated study as all electricity should be based on coal condensing plants.

The main contribution to the category "bulk waste" in the previous study is energy consumption and depositing of the packaging. In the previous study it was assumed that 20% of the household waste were deposited at landfills (due to practise in 1992-93 in Denmark), but in the updated study, the mixed household waste is assumed to be incinerated. Incineration is identified as the marginal technology for household waste management since landfilling of combustible waste is no longer allowed. Hence, it is assumed that the main part of "bulk waste" in the updating will be due mainly to energy consumption.

In the previous study the waste category "hazardous waste" is both due to energy consumption and process related wastes (namely in the systems for aluminium cans and steel cans).

A.2.3 Changes with influence on all the systems

The changes in the updating that have the very significant influences on the results are the energy systems and the allocation methods. These two changes have significant influence on the results of most of the packaging systems.

Preconditions for the energy scenarios

In the previous study the energy scenarios where based on the site specific approach and in the updated study it is based on the marginal approach. For further description, see the Main report, section 2.9.

Allocation method

In the previous study the 50/50 allocation method was used, in the updated study the ISO and EDIP method is used. The allocation procedures of the updated study are described in the main report. The corresponding description for the previous study is made in chapter 4 of Pommer and Wesnaes (1995).

A.3 Refillable glass bottles

The conclusions regarding refillable glass bottles for beer (33 cl, green glass) and refillable glass bottles for soft drinks (25 cl, clear glass) are the same. The relative significance of the processes in the system for 25 cl clear bottles and 33 cl green bottles are very much alike. The 25 cl bottles use slightly more glass per 1000 litres of beverage, and the relative contribution from the labels and bottle caps are slightly higher for the 25 cl bottles than for the 33 cl bottles (due to the use of respectively 4000 and 3030 labels and caps per 1000 litres). This however, has no significance for the conclusions of the comparison between the previous study and the updated study.

Hence only the beer bottles will be used as an illustration in this chapter.

A.3.1 Results of the comparison

The total emissions of CO_2, SO_2, NO_x and volatile organic compounds from the previous and updated study for 33 cl refillable glass bottles are shown in tableA.2 per 1000 litres of beer. The emissions are shown as net amounts (*i.e.* the total contribution minus the avoided emissions).

Table A.2
Total emissions of CO_2, SO_2, NO_x and volatile organic compounds from the previous and updated study for 33 cl refillable glass bottles. Emissions per 1000 litres of beer. The results are rounded.

	Previous study	Updated study
CO_2 (kg)	≈ 220 kg	≈ 160 kg
SO_2 (gram)	≈ 1400 g	≈ 250 g
NO_x (gram)	≈ 1600 g	NO_x ≈ 620 g
NO_2 (gram)		NO_2 ≈ 40 g
		Total NO_x ≈ 660 g
VOC's (gram)	≈ 1100 g	NMVOC's ≈ 120 g
		VOC's ≈ 50 g
		Other specified VOC's ≈ 1 g
		Total VOC's ≈ 170 g

A.3.2 Carbon dioxide

As can be seen from table A.2 the total emissions of CO_2 are lower in the updated study (160 kg) than in the previous study (220 kg), corresponding to a reduction of approximately 25% of the net CO_2 emissions from the previous study.

The processes which have the main significance for the reduction are mentioned below. Some of the processes have lower contributions of CO_2 in the updated study, and some higher. The percentages given below are related to the net CO_2 emissions in the previous study (*i.e.* 220 kg).

- Washing and filling the bottles at the breweries (reduction of 9%)
- Distribution (reduction of 15%)
- Avoided emissions due to incineration of pallets (reduction of 3%)

The remaining processes contribute to changes in the level of 1-2% or less.

Washing and filling

The reduction of the CO_2 emissions from washing and filling the bottles at the breweries is due to:

- a shift in fuel source at the breweries, and
- the emission factor used for these fuel sources.

In the previous study, the breweries used fuel oil for producing heat for washing and pasteurising (according to the collected data in 1993). In the updated study, the fuel source for this is natural gas. The emission factor used for heat produced by combustion of fuel oil (in gram CO_2 per MJ) in the previous study is almost twice as high as the emission factor used for producing heat by combustion of natural gas and this results in a reduction of the CO_2 emissions.

The CO_2 emissions are reduced despite the fact the heat demand for the soft drink bottles is higher in the update. The heat demand for the beer bottles are lower in the update. The CO_2 emissions from the electricity are at the same level as the previous study as described under "electricity production" below.

Distribution

The calculations of the distribution of beer have been changed significantly from the previous study to the updated study. In the previous study the transport was calculated as the transported weight multiplied by the transport distance multiplied by a emission factor. In the updated study the transport during distribution has been specified, *i.e.* identifying transport vehicles, transport modes (*i.e.* drive on highways, under rural or urban circumstances). The fuel consumption (per ton-km) is significantly lower in the update. The trucks used for the distribution are mainly medium or large sized trucks. The fuel consumption used in the previous study corresponds to small sized trucks.

The reduced fuel consumption is partly offset by the fact that the update includes distribution not only of the packaging but also of the beverage. For the other systems, the reduced fuel consumption is more than offset by this. As explained in section A.2.5, the distribution of the beverage is included in the updated comparison because the choice of packaging system affects the efficiency of the beverage distribution.

For further description, see Technical report 7.

The specification of the transport has resulted in a significant reduction of the CO_2 emissions from the distribution although transport of beer is included in the updated study (which it was not in the previous study).

Avoided emissions due to incineration of pallets

The life cycle of pallets are included in the updated study which it was not in the previous study. The production of wood and pallets have almost no significance, but the avoided emissions due to incineration of pallets reduces the total CO_2 emissions significantly compared to the previous study.

System boundaries for recycled glass

The previous study and the updated study have different system boundaries for the use of recycled glass and the production of recycled glass within the system. However, this has almost no significance for the refillable glass bottles for beer. This is further discussed in chapter A.4, as the significance for the disposable glass bottles are higher.

Electricity production

It should be noted that a large share of the carbon dioxide (in the system for refillable 33 cl glass bottles) arises from electricity production in Denmark according to the previous study. In the previous study, Danish electricity production were mainly based on coal fired electricity plants. Consequently, the change of energy scenarios in the updated study into a marginal approach of coal condensing plants has only little influence on the emissions.

A.3.3 Sulphur dioxide

As can be seen from table A.2 the net emissions of SO_2 are significantly lower in the updated study (250 gram) than in the previous study (1380 gram), corresponding to a reduction of approximately 82% of the net SO_2 emissions from the previous study.

The processes which have the main significance for the difference of the SO_2 emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net SO_2 emissions in the previous study (*i.e.* 1380 gram).

The processes with the main significance for the reduction are:
Washing and filling the bottles at the breweries (reduction of 63%)

- Distribution (reduction of 5%)
- Production of labels (reduction of 6%)
- Production of caps (reduction of 4%)

The remaining processes contribute to changes in the level of 1-2% or less.

Washing and filling

The reduction of the SO_2 emissions from washing and filling the bottles at the breweries is due to the shift in fuel source at the breweries, as mentioned earlier (section A.3.2 Carbon dioxide). In the previous study the breweries used fuel oil for producing heat for washing and pasteurising, and in the updated study the fuel source for this is natural gas. Fuel oil contains sulphur, which Danish natural gas does not.

Distribution

The SO_2 emissions from the distribution are reduced in the updated study when comparing with the previous study. This is due to the more specified data used in the updated study, see section A.3.2 Carbon dioxide. It should be noted that it has been specified that the trucks used in 1997 drives on "diesel, light" with a significant lower sulphur content.

Labels

The reduction of the SO_2 emissions from the labels is due to new data on paper production.

Caps

The reduction of the SO_2 emissions from the caps is due to new data sources.

A.3.4 Nitrogen oxides

As can be seen from table A.2 the net emissions of NO_X are significantly lower in the updated study (660 gram) than in the previous study (1560 gram), corresponding to a reduction of approximately 57% of the net NO_x emissions from the previous study.

The processes which have the main differences of NO_x emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net NO_x emissions in the previous study (*i.e.* 1560 gram).

The processes that cause the main differences are:

- Washing and filling the bottles at the breweries (reduction of 6%)
- Transport during distribution of beer (reduction of 54%)

The remaining processes contribute to changes in the level of 1-2% or less.

The explanations are the same as for CO_2, see section A.3.2.

A.3.5 Volatile organic compounds

As can be seen from table A.2 the net emissions of VOCs are significantly lower in the updated study (170 gram) than in the previous study (600 gram), corresponding to a reduction of approximately 72% of the net VOC emissions from the previous study.

The processes which have the main significance for the difference of the VOC emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net VOC emissions in the previous study (*i.e.* 600 gram).

The processes that cause the main differences are:

- Washing and filling the bottles at the breweries (reduction of 21%)
- Transport during distribution of beer (reduction of 47%)
- Avoided emissions due to incineration of pallets (reduction of 4%)

The remaining processes contribute to changes in the level of 1-2% or less. The explanations are the same as for CO_2, see section A.3.2.

A.4 Disposable glass bottles

In general, the main results of the comparison of the previous study and the updated study are the same for disposable glass bottles for beer and for soft drinks (both 33 cl). The main difference between the green glass bottles for beer and the clear glass bottles for soft drinks is that the use of broken glass pieces is significantly higher when producing clear glass. Furthermore, green glass and clear glass does not contain exactly the same raw materials, but this has no influence on this comparison.

In the previous study, there was one more significant difference: The beer bottles were equipped with a bottle cap of tin-plate and the soft drink bottles with a screw cap of HDPE. In the updated study both types of bottles have tin-plate bottle caps.

In this chapter the green glass bottles for beer is described, and only when the results of the clear glass bottles for soft drink are considerably different from the results of the beer bottles, they are mentioned.

A.4.1 Results of the comparison

The total emissions of CO_2, SO_2, NO_x and VOCs from the previous and updated study for 33 cl disposable green glass bottles are shown in table A.3 per 1000 litres of beer. The emissions are shown as net emissions (*i.e.* the total contributions minus the total avoided emissions).

Table A.3
Net emissions of CO_2, SO_2, NO_X and VOCs from the previous and updated study for 33 cl disposable green glass bottles. Emissions per 1000 litres of beer. The results are rounded.

	Previous study	Updated study
CO_2 (kg)	≈ 400 kg	≈ 340 kg
SO_2 (gram)	≈ 2380 g	≈ 950 g
NO_X (gram)	≈ 1840 g	NO_X ≈ 1060 g
NO_2 (gram)		NO_2 ≈ 760 g
		Total NO_X ≈ 1810 g
VOCs (gram)	≈ 600 g	NMVOC's ≈ 200 g
		VOC's ≈ 64 g
		"Other specified VOC's ≈ 0 g
		Total VOCs ≈ 260 g

A.4.2 Carbon dioxide

As can be seen from table A.3 the net emissions of CO_2 are lower in the updated study (340 kg) than in the previous study (400 kg), corresponding to a reduction of approximately 15% of the net CO_2 emissions from the previous study.

The processes with the main significance for the difference are mentioned below. Some of the processes has an lower contribution of CO_2 in the updated study, and some a higher contribution. The percentages given below are related to the net CO_2 emissions in the previous study (*i.e.* 400 kg).

The processes which cause the main differences are:

- Filling the bottles at the breweries (reduction of 11%)
- Production of cardboard trays (reduction of 11%)
- Avoided emissions due to incineration (increase of 6%)
- Emissions from incineration of PE, paper and cardboard (increase of 7%)
- Transport: Distribution of beer (increase of 2%)
- Transport: Other, total (reduction of 2%)
- Avoided emissions caused by recycling of broken glass pieces (Green glass bottles for beer: increase of 1%. Clear glass bottles for soft drink: reduction of 8%)

The remaining processes contribute to changes in the level of 1-2% or less.

For the clear glass bottles for soft drink the following should be mentioned:

- Production of caps (reduction of 5%)
- Incineration of caps (increase of 14%)

Filling at the breweries

The energy for filling the bottles at the breweries are significantly lower in the updated study (32 MJ electricity per 3030 bottles) than in the previous study (180 MJ electricity per 3030 bottles) due to new information from the breweries. This results in a significant lower contribution of CO_2.

Production of cardboard trays

The contribution of CO_2 from the production of the cardboard trays are significantly lower in the updated study than in the previous study. This is partly due to a reduction of the weight of cardboard per 3030 bottles and mainly due to new data on production of cardboard.

Avoided emissions from waste incineration

The avoided emissions caused by the utilisation of the energy produced at waste incineration plants when incinerating PE, paper and cardboard are significant lower in the updated study. This results in that the *total* emissions of CO_2 are *higher* in the updated study for this process. The difference is mainly due to the assumptions of substitution of energy source. In the previous study, it was assumed that the produced heat substituted Danish electricity (which is not correct). In the updated study, the produced heat mainly replaces district heating, avoiding natural gas and oil heaters in private households.

Furthermore, the updating includes wooden pallets and avoided emissions from incinerating these (the previous study did not include wooden pallets). This results in that the total emissions of CO_2 are slightly higher in the updated study.

Emissions from incineration

The emissions of CO_2 from incineration of PE were not included in the previous report, which they should have been. The inclusion of these in the updating contributes to higher total emission of CO_2.

Transport (and distribution)

The emissions of CO_2 from the distribution are higher in the updated study than in the previous study, due to the inclusion of transport of the beverage. However, it should be noted, that this has only little influence on the overall results. The emissions of CO_2 from other transports within the system (seen as a total) are lower in the updated study due to new emission factors for the transport, see section A.3.2.

Production of caps

Two processes are significant for the clear glass bottles for *soft drink* only: The production of caps and the avoided emissions from incineration of the caps. As mentioned in the introduction of this chapter, the glass bottles had HDPE screw caps in the previous study and in the updated study the caps are of tin-plate. This leads to slightly lower emissions of CO_2 from the production of caps in the updated study. On the contrary, the avoided emissions from incineration of the caps are lower in the updating, leading to an overall *higher* total contribution of CO_2 from the caps in the updated study.

Avoided emissions due to recycling of glass

The previous study was based on the following assumptions: 90% of the glass bottles are returned by the consumer. The glass production on Holmegaard Glass works utilised a maximum of 85% broken glass pieces for green glass (and 50% for clear glass). This left a net *surplus* of broken glass pieces of 5% from the system of green glass bottles (and 40% from the system of clear glass bottles). According to the allocation in the previous study, the systems obtained a credit of 50% of the extraction of raw materials corresponding to this surplus of broken glass bottles (corrected with a factor little larger than 1 because the consumption of raw materials are more than 1 kg per kg glass). This credit had no practical significance for the green glass bottles for beer. For the clear glass bottles, the credit was in the magnitude of 5% of the total emissions of CO_2.

In the updated study the net avoided emissions of CO_2 is also negligible for the disposable green glass bottles for beer (interpreted as the sum of the processes named "Recycled glass", "Broken glass bottles" and "Virgin glass (avoided)"). For the clear glass bottles for soft drink, the net avoided emissions of CO_2 are higher in the updated study than in the previous study.

A.4.3 Sulphur dioxide

As can be seen from table A.3 the net emissions of SO_2 are significantly lower in the updated study (950 gram) than in the previous study (2380 gram), corresponding to a reduction of approximately 60% of the net SO_2 emissions in the previous study.

The processes with the main significance for the difference of the SO_2 emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net SO_2 emissions in the previous study (*i.e.* 2380 gram).

The processes that cause the main differences are:

- Production of glass (reduction of 16%)
- Filling the bottles at the breweries (reduction of 9%)
- Production of paper and cardboard trays (reduction of 28%)
- Production of paper (reduction of 4%)
- Production of caps (reduction of 3%)
- Avoided emissions due to incineration (increase of 8%)
- Transport: Other, total (reduction of 1%)

The remaining processes contribute to changes in the level of 1-2% or less.

For the clear glass bottles for soft drink the production and incineration of caps and the avoided emissions caused by recycling of broken glass pieces lead to significant differences in the SO_2 emissions, as described for CO_2 in section A.4.2.

Production of glass

The contribution of SO_2 from the production of glass at the glass works are significantly lower in the updated study. This is due a lower weight of the bottle (hence fewer kg glass is produced per 3030 bottles) combined with lower emissions of SO_2 per kg glass from Holmegaard Glass works. Holmegaard Glass works has increased focus on and control with sulphate in the broken glass pieces and the melted glass resulting in lower SO_2 emissions. It could be noted, that Holmegaard Glassworks are working on building a filter which will result in further significant reductions of the SO_2 emissions.

Production of cardboard trays and labels

The contribution of SO_2 from the production of the cardboard trays and labels are significantly lower in the updated study. Actually, these processes cause the biggest reduction of the total SO_2 emissions when comparing the previous study and the updating. As mentioned for cardboard trays in section A.4.2 this is mainly due to new data on cardboard production. This also applies for the paper production for labels.

The remaining processes

The explanations for the remaining processes are the same as for CO_2, see section A.4.2.

A.4.4 Nitrogen oxides

As can be seen from table A.3 the net emissions of NO_x are at the same level in the two studies. This is because some of the processes in the updated study contribute less and some more than in the previous study.

The processes with the main differences of NO_x emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net NO_x emissions in the previous study (*i.e.* 1840 gram).

The processes that cause the main differences are:

- Production of glass (increase of 14%)
- Filling the bottles at the breweries (reduction of 6%)
- Production of cardboard trays (reduction of 7%)
- Avoided emissions due to incineration (increase of 6%)
- Emissions from incineration of PE, paper and cardboard (increase of 5%)
- Transport: Other, total (reduction of 15%)

The remaining processes contribute to changes in the level of 1-2% or less.

Production of glass

The contribution of NO_x from the production of glass at the glass works are higher in the updated study. This is due to higher consumption of energy (both natural gas and electricity) per kg glass combined with higher emissions of NO_x per kg glass from Holmegaard Glass works.

The remaining processes

The explanations for the remaining processes are the same as for CO_2, see section A.4.2.

A.4.5 Volatile organic compounds

As can be seen from table A.3 the net emissions of VOCs are significantly lower in the updated study (260 gram) than in the previous study (600 gram), corresponding to a reduction of approximately 56% of the net VOC emissions in the previous study.

The processes with the main significance for the difference of the VOC emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net VOC emissions in the previous study (*i.e.* 600 gram).

- The processes that cause the main differences are:
- Extraction of raw materials (increase of 5%)
- Production of glass (reduction of 4%)
- Production of labels (reduction of 4%)
- Production of cardboard trays (reduction of 30%)
- Avoided emissions due to incineration (increase of 5%)
- Transport: Other, total (reduction of 17%)

The remaining processes contribute to changes in the level of 1-2% or less.

Production of glass

The VOC emissions caused by the production of glass arises from the consumption of energy, hence the change is caused by updating of emission factors for electricity production and production of natural gas.

The remaining processes

The explanations for the remaining processes are the same as for CO_2, see section A.4.2.

A.5 Aluminium cans

The overall conclusions regarding aluminium cans of 33 cl and 50 cl are the same (although the differences in percentages are not always exactly the same). Hence, the 33 cl cans are used as an illustration in this chapter.

A.5.1 Results of the comparison

The total emissions of CO_2, SO_2, NO_x and VOCs in the previous and updated study for 33 cl aluminium cans are shown in table A.4 per 1000 litres of soft drink. The emissions are shown as net amounts (*i.e.* the total contribution minus the avoided emissions).

Table A.4
Total emissions of CO_2, SO_2, NO_x and VOCs in the previous and updated study for 33 cl aluminium cans. Emissions per 1000 litres of beverage. The results are rounded.

	Previous study	Updated study
CO_2 (kg)	≈ 110 kg	≈ 340 kg
SO_2 (gram)	≈ 1160 g	≈ 800 g
NO_x (gram)	≈ 430 g	≈ 1250 g
VOCs (gram)	≈ 480 g	NMVOC ≈ 144 g VOC ≈ 76 g Other specified VOC ≈ 1 g Total VOCs ≈ 220 g

A.5.2 Carbon dioxide

The total emissions of CO_2 are significantly higher in the updated study (340 kg) than in the previous study (110 kg), corresponding to a increase of approximately 210% of the net CO_2 emissions in the previous study.

The processes with the main significance for the difference are mentioned below. Some of the processes have lower contribution of CO_2 in the updated study, and some higher contribution. The percentages given below are related to the net CO_2 emissions in the previous study (*i.e.* 110 kg).

- The processes that cause the main differences are:
- Extraction of raw materials (reduction of 4%)
- Production of aluminium (increase of 68%)
- Production of aluminium cans (increase of 43%)
- Production of methyl acrylate and epoxy resins (increase of 16%)
- Filling at breweries (reduction of 10%)
- Distribution (increase of 14%)
- Transport, total (other than distribution) (increase of 7%)
- Recovering of aluminium (increase of 61%)
- Production of Hi-cone (reduction of 4%)
- Production of cardboard trays etc. (reduction of 37%)
- Emissions from incineration (increase of 4%)
- Avoided emissions from waste incineration (increase of 26%)

Extraction of raw materials

The CO_2 emissions from the extraction of raw materials, bauxite mining and production of alumina (Al_2O_3) is slightly lower in the updated study due to new data sources.

Production of aluminium

The total emissions of CO_2 for this process is significantly higher in the updating. This is mainly due to that the electricity production for the process was based on hydro power in the previous study and on coal fired power plants in the updated study. The process is very electricity consuming.

Furthermore, the production of aluminium is slightly higher in the updated study due to that *all* the aluminium consumption is calculated as primary aluminium in the updating, corresponding to 12%. In the previous study it was assumed that at least 25% of the lids for the cans had to consist of primary aluminium (corresponding to 6.25% of the total can for 33 cl cans) based on information from the can producers. Furthermore, secondary aluminium were supplied to the system, using the 50/50 allocation method (hence the system had to pay for 50% of the production of primary aluminium and extraction of raw materials). Hence, a greater amount is calculated as primary aluminium in the updating. In both studies, it is assumed that the amount of cans returned by the consumer (90%) are recycled in a closed loop, see recovering of aluminium below.

Aluminium cans

The CO_2 emissions are higher in the updating in spite of that the energy consumption per 3030 cans is significantly lower in the updating (the electricity consumption has decreased by approximately 12% and the consumption of natural gas has decreased by approximately 40%). The CO_2 emissions from the production of aluminium cans are higher in the updating. The increase in CO_2 emissions is due to the fact that the electricity production for the process was assumed to be average Swedish electricity production (mainly hydropower and nuclear power) in the previous study. In the base case scenario of the updated study, the electricity production affected is assumed to be coal fired power plants.

Methyl acrylate and epoxy resins

The production of methyl acrylate and epoxy resins are included in the updated study, which it was not in the previous study. Methyl acrylate and epoxy resins are used as respectively over-varnish and inside coating for the surface treatment of the cans. This has increased the energy consumption and the emissions of the system significantly.

Filling at breweries

The CO_2 emissions from filling the cans with beverage at the breweries is reduced significantly. This is due to reduction of the electricity consumption and a change of energy source. In the previous study the process required electricity (55 MJ per 3030 cans) and no heat (based on information from the breweries). In the updating, the breweries have estimated a significantly lower electricity consumption (8 MJ per 3030 cans) and in addition to this a consumption of natural gas (53 MJ per 3030 cans).

Distribution

The CO_2 emissions from the distribution have increased significantly as a consequence of including the beverage in the transport. In the previous study, only the weight of the packaging and secondary packaging were included.

Other transport

The CO_2 emissions from transport, calculated as a total of all the transport in the system but the distribution, has increased. It is mainly due to a higher number of transports. According to the results of the other systems, the emission factor for transport is in general lower, hence it is not due to updating of this.

Recovering of aluminium

The CO_2 emissions from the recovering processes seems to have increased significantly. As for the production of aluminium cans, this is due to the change of electricity production (*i.e.* Swedish electricity production (mainly hydropower and nuclear power) in the previous study and coal fired power plants in the updated study). The emissions are increased in spite of the consumption of electricity and heat (based on LPG) per kg remelted aluminium being reduced significantly and in spite of the remelted amounts of aluminium being reduced significantly as the aluminium scrap from strip rolling has reduced notable.

Production of Hi-cone

The slight reduction of the CO_2 emissions from producing LDPE for hi-cones and foil is caused by a combination of reduced weight of LDPE per 3030 cans combined and new data sources.

Production of cardboard trays

The CO_2 emissions from the production of cardboard trays and boxes are reduced significantly, mainly due to a significant reduction of the weight of cardboard per 3030 cans. Furthermore, the use of new data sources cause differences.

Emissions from incineration

The emissions from incineration of the packaging materials has increased slightly for that simple reason that they are included in the updated study but were not in the previous study.

Avoided emissions from from waste incineration

The "avoided CO_2 emissions" from the energy production at the waste incineration plants when incinerating the used packaging materials are lower in the updated study. This contributes to that the total emissions of CO_2 are significantly higher in the updated study. This is mainly due to the assumption that the produced energy replaced Danish electricity in the previous study (which was not correct). In the updated study the energy mainly replaces combustion of natural gas and oil at private households.

Furthermore, the produced energy was very dominated by the incineration of cardboard boxes. As described above, the weight of cardboard for secondary packaging has been reduced significantly, hence, the energy from incineration and the avoided emissions are reduced accordingly.

A.5.3 Sulphur dioxide

As can be seen from table A.4 the net emissions of SO_2 are significantly lower in the updated study (800 gram) than in the previous study (1160 gram), corresponding to a reduction of approximately 31% of the net SO_2 emissions in the previous study.

The processes with the main significance for the difference of the SO_2 emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net SO_2 emissions in the previous study (*i.e.* 1160 gram).

The processes that cause the main differences are:

- Extraction of raw materials (reduction of 12%)
- Production of aluminium (increase of 8%)
- Production of aluminium cans (increase of 6%)
- Production of methyl acrylate and epoxy resins (increase of 3%)
- Filling at breweries (reduction of 6%)
- Distribution (increase of 2%)
- Transport, total (other than distribution) (increase of 4%)
- Recovering of aluminium (increase of 4%)
- Production of Hi-cone (reduction of 4%)
- Production of cardboard trays etc. (reduction of 57%)
- Emissions from incineration (increase of 4%)
- Avoided emissions from waste incineration (increase of 21%)

Washing and filling

As mentioned in section A.3.2 the breweries have shifted from heat produced by fuel oil to heat produced by natural gas. Fuel oil contains sulphur, which Danish natural gas does not, hence the emissions of SO_2 is reduced.

The remaining processes

The explanations for the remaining processes are given in section A.5.2 Carbon dioxide.

A.5.4 Nitrogen oxides

As can be seen from table A.4 the net emissions of NO_X are significant higher in the updated study (1250 gram) than in the previous study (430 gram), corresponding to a increase of approximately 190% of the net NO_x emissions in the previous study.

The processes with the main significance for the difference of the NO_x emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net NO_x emissions in the previous study (*i.e.* 430 gram).

The processes that cause the main differences are:

- Extraction of raw materials (reduction of 6%)
- Production of aluminium (increase of 40%)
- Production of aluminium cans (increase of 37%)
- Production of methyl acrylate and epoxy resins (increase of 9%)
- Filling at breweries (reduction of 8%)
- Distribution (increase of 31%)
- Transport, total (other than distribution) (increase of 26%)
- Recovering of aluminium (increase of 45%)
- Production of cardboard trays etc. (reduction of 28%)
- Emissions from incineration (increase of 6%)
- Avoided emissions from waste incineration (increase of 29%)

The explanations are given in section A.5.2 and 5.3.

A.5.5 Volatile organic compounds

As can be seen from table A.4 the net emissions of VOCs are lower in the updated study (220 gram) than in the previous study (480 gram), corresponding to a reduction of approximately 54% of the net VOC emissions in the previous study.

The processes with the main significance for the difference of the VOC emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net VOC emissions in the previous study (*i.e.* 480 gram).

The processes that cause the main differences are:

- Extraction of raw materials (reduction of 7%)
- Production of aluminium (reduction of 2%)
- Production of aluminium cans (reduction of 8%)
- Production of methyl acrylate and epoxy resins (increase of 7%)
- Distribution (increase of 12%)
- Transport, total (other than distribution) (increase of 2%)
- Recovering of aluminium (reduction of 2%)
- Production of Hi-cone (increase of 2%)
- Production of cardboard trays etc. (reduction of 37%)
- Avoided emissions from waste incineration (reduction of 7%)

Aluminium cans

The total emissions of VOCs from the production of aluminium cans are lower in the updated study in spite of the change of electricity production, as explained in section A.5.2. This is due to a significant reduction of VOCs from the lacquering of the cans per 3030 cans. The main contributor is butanol. In the previous study the amounts of butanol was 81 gram per 3030 cans. In the updating, this has been reduced to 20.9 gram per 3030 cans according to PLM in Sweden.

Avoided emissions from waste incineration

The avoided VOC emissions from waste incineration is higher in the updated study in spite of that less energy is produced from incineration of cardboard and in spite of the change of avoided energy production from electricity to household oil and natural gas boilers, as explained in section A.5.2. The difference is caused by the updated data set.

A.6 Steel cans

The overall conclusions regarding steel cans of 33 cl and 50 cl are the same (although the differences in percentages are not always exactly the same). The main difference between the systems are that there are used more steel and aluminium per 1000 litres of beverage for the 33 cl cans, hence the significance of processing of the metals and producing the can has bigger significance for the 33 cl cans than for the 50 cl cans. Hence, the 33 cl cans are used as an illustration in this chapter.

A.6.1 Results of the comparison

The total emissions of CO_2, SO_2, NO_x and VOCs in the previous and updated study for 33 cl aluminium cans are shown in table A.5 per 1000 litres of soft drink. The emissions are shown as net amounts (*i.e.* the total contribution minus the avoided emissions).

Table A.5

Total emissions of CO_2, SO_2, NO_x and VOCs in the previous and updated study for 33 cl steel cans. Emissions per 1000 litres of beverage. The results are rounded.

	Previous study	Updated study
CO_2 (kg)	≈ 380 kg	≈ 400 kg
SO_2 (gram)	≈ 3010 g	≈ 1050 g
NO_x (gram)	≈ 1220 g	≈ 1500 g
VOCs (gram)	≈ 830 g	NMVOC ≈ 174 g VOC ≈ 94 g Other specified VOC ≈ 1 g Total VOCs ≈ 270 g

A.6.2 Carbon dioxide

The total emissions of CO_2 are a little higher in the updated study (400 kg) than in the previous study (380 kg), corresponding to a increase of approximately 5% of the net CO_2 emissions in the previous study.

The processes with the significant differences are mentioned below. Some of the processes have an lower contribution of CO_2 in the updated study, and some higher contribution. The percentages given below are related to the net CO_2 emissions in the previous study (*i.e.* 380 kg).

The processes that cause the main differences are:

- Production and recycling of steel (reduction of 32%)
- Extraction of raw materials, production of aluminium and production of the lid (as a total) (increase of 36%)
- Filling at breweries (reduction of 3%)
- Distribution (increase of 4%)
- Transport, total (other than distribution) (increase of 2%)
- Production of Hi-cone (reduction of 1%)
- Production of cardboard trays etc. (reduction of 11%)
- Emissions from incineration (increase of 1%)
- Avoided emissions from waste incineration (increase of 7%)

Production and recycling of steel

It is not possible to compare the individual processes of the production of steel, production of steel cans, recycling of steel and avoided emissions due to allocation procedures (*i.e.* avoiding allocation in the updating) as the model for the steel cans system is very different in the updating compared to the previous system (*e.g.* are processes for the iron production and the production of steel cans combined in the updating and it is not possible to identify the relative contributions). Hence, it has only been possible to make an comparison based on sum of the contributions from all the processes related to steel processing.

For the previous study that means the sum of the processes named:

- Production of steel based on iron ore
- Production of steel based on steel scrap
- Production of steel cans
- Recycling of steel

For the updating that means the sum of the processes named:

- 2. Lime
- 4. Limestone
- 6. Tin (*i.e.* extraction of tin ore and refining of tin)
- 8. H_2SO_4
- 10. Iron ore extraction
- 1. Tinplate cans
- 61. BOF recycling
- 62. Steel scrap market
- 66. Avoided steel production
- 67. EAF recycling
- 86. EAF recycling
- 88. Avoided steel production

It should be noted that the CO_2 emissions of the previous study are markedly too low as no CO_2 emissions from the steel production were included due to data lack. Considerable amounts of coal is used in the basic oxygen furnace (BOF) giving CO_2 when incinerated.

When comparing the sum of these processes the total CO_2 emissions are significant lower in the updated study. The explanation is not clear. However, it should be remarked, that the steel data were old and probably considerable too high. The data for the steel processes in the previous study was based on BUWAL (1990) due to lack of site specific data from steel works in Europe. According to BUWAL (1990) the employed data for steel production is based on literature data, where the data on energy are mainly based on data from 1998 and 1989, and the emission data are based on data from 1974-75. Hence, it is presumed, that the data in the updating to a large extent is a far better description of the steel processes.

The remaining processes

The explanations of the remaining processes are the same as the explanations for aluminium cans, see chapter A.5.

A.6.3 Sulphur dioxide

As can be seen from table A.5 the net emissions of SO_2 are significantly lower in the updated study (1050 gram) than in the previous study (3010 gram), corresponding to a reduction of approximately 65% of the net SO_2 emissions in the previous study.

The processes with the main significance for the difference of the SO_2 emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net SO_2 emissions in the previous study (*i.e.* 3010 gram).

The processes that cause the main differences are:

- Production and recycling of steel (reduction of 12%)
- Extraction of raw materials, production of aluminium and production of the lid (as a total) (increase of 2%)
- Filling at breweries (reduction of 2%)
- Transport, total (other than distribution) (increase of 2%)
- Production of Hi-cone (reduction of 1%)
- Production of cardboard trays etc. (reduction of 22%)
- Avoided emissions from waste incineration (increase of 6%)

The explanations for are given in section A.6.2 and in chapter A.5.

A.6.4 Nitrogen oxides

As can be seen from table A.5 the net emissions of NO_x are significant higher in the updated study (1500 gram) than in the previous study (1220 gram), corresponding to a increase of approximately 23% of the net NO_x emissions in the previous study.

The processes with the main significance for the difference of the NO_x emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net NO_x emissions in the previous study (*i.e.* 1220 gram).

The processes that cause the main differences are:

- Production and recycling of steel (increase of 5%)
- Extraction of raw materials, production of aluminium and production of the lid (as a total) (increase of 35%)
- Filling at breweries (reduction of 3%)
- Distribution (increase of 10%)
- Transport, total (other than distribution) (increase of 4%)
- Production of cardboard trays etc. (reduction of 10%)
- Emissions from incineration (increase of 4%)
- Avoided emissions from waste incineration (increase of 8%)

The explanations are given in section A.6.2 and chapter A.5.

A.6.5 Volatile organic compounds

As can be seen from table A.5 the net emissions of VOCs are lower in the updated study (270 gram) than in the previous study (830 gram), corresponding to a reduction of approximately 68% of the net VOC emissions in the previous study.

The processes with the main significance for the difference of the VOC emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net VOC emissions in the previous study (*i.e.* 830 gram).

- The processes that cause the main differences are:
- Production and recycling of steel (reduction of 16%)
- Extraction of raw materials, production of aluminium and production of the lid (as a total) (reduction of 4%)
- Distribution (increase of 6%)
- Transport, total (other than distribution) (reduction of 8%)
- Production of Hi-cone (increase of 1%)
- Production of cardboard trays etc. (reduction of 22%)
- Emissions from incineration (increase of 1%)
- Avoided emissions from waste incineration (reduction of 3%)

The explanations are given in section A.6.2 and chapter A.5.

A.7 Refillable PET bottles

The overall conclusions regarding refillable PET bottles of 50 cl and 150 cl are the same (although the differences in percentages are not always exactly the same). The main difference between the 50 cl and 150 cl is that the differences regarding the screw caps have bigger significance for the 50 cl bottles as there are used 3 times as many screw caps per 1000 litres of soft drink. Hence, the 150 cl bottles will be used as an illustration in this chapter.

A.7.1 Results of the comparison

The total emissions of CO_2, SO_2, NO_x and VOCs in the previous and updated study for 150 cl refillable PET bottles are shown in table A.6 per 1000 litres of soft drink. The emissions are shown as the amounts (*i.e.* the total contribution minus the avoided emissions).

Table A.6

Total emissions of CO_2, SO_2, NO_x and VOCs in the previous and updated study for 150 cl refillable PET bottles. Emissions per 1000 litres of soft drink. The results are rounded.

	Previous study	Updated study
CO_2 (kg)	≈ 96 kg	≈ 65 kg
SO_2 (gram)	≈ 760 g	≈ 190 g
NO_x (gram) NO_2 (gram)	≈ 440 g	≈ 370 g
VOCs (gram)	≈ 230 g	NMVOC ≈ 73 g VOC ≈ 116 g Other specified VOC ≈ 0 g Total VOCs ≈ 190 g

A.7.2 Carbon dioxide

The total emissions of CO_2 are lower in the updated study (65 kg) than in the previous study (95 kg), corresponding to a reduction of approximately 33% of the net CO_2 emissions in the previous study.

The processes with the main significance for the difference are mentioned below. Some of the processes has a lower contribution of CO_2 in the updated study, and some a higher contribution. The percentages given below are related to the net CO_2 emissions in the previous study (*i.e.* 95 kg).

The processes that cause the main differences are:

- Production of PET granulates (reduction of 11%)
- Washing and filling (reduction of 29%)
- Distribution (increase of 11%)
- Production of screw caps (reduction of 5%)
- Production of labels (reduction of 2%)
- Avoided emissions from waste incineration (increase of 4%)
- Avoided PET production (reduction of 3%)
- Avoided energy production from recycled PET (increase of 4%)

Production of PET granulate

The production of PET granulate includes all the processes from extraction and refining of raw materials until and including processing of the PET granulate. The emissions of CO_2 from the production of PET are notably lower in the updated study than in the previous study. The difference is due to the use of updated data for the PET production and for the energy production.

Washing and filling

The reduction of the CO_2 emissions from the washing and filling of the PET bottles is due to the same reasons as for refillable glass bottles, as the soft drink producers seem to have shifted from heat produced by fuel oil to heat produced by natural gas as the breweries, see section A.3.2. The electricity consumption for washing and filling is slightly higher per 1000 litres of soft drink in the updating, but the energy consumption for heating is reduced by nearly 50% in the updating, resulting in lower CO_2 emissions.

Distribution

In contrast to the refillable glass bottles, the contribution of CO_2 from the distribution has increased for the refillable PET bottles. The emission factors are reduced for both systems. However, the transport of the beverage (1000 litres) is included in the updating, and for the PET bottles this increases the total distributed weight significantly, hence resulting in a net increase of CO_2.

Production of screw caps

The CO_2 emissions from the production of screw caps are lower in the updated study. This is partly due to a reduction of the total weight of the screw cap inclusive insert (2.8 gram in the previous study, 2.2 gram in the updated study). Part of the change is due to the use of updated data for the production of polypropylene.

Production of labels

The CO_2 emissions from the production of labels is slightly lower in the updated study. This is due to the use of updated data for paper production.

Avoided emissions from waste incineration

The "avoided CO_2 emissions" from the energy production at the waste incineration plants when incinerating the used packaging materials are lower in the updated study. This is mainly due the assumption that the produced energy replaced Danish electricity in the previous study (which was not correct). In the updated study, the energy mainly replaces combustion of natural gas and oil at private households.

Avoided PET production

In the updated study it is assumed that 50% of the recycled PET replaces virgin PET, hence avoiding the production of this. In the previous study it was assumed that the recycled PET were of such low quality that it could not replace virgin PET in any degree, hence the system for PET bottles obtained no compensation for recycling. This difference results in a lower total contribution of CO_2 emissions for the updated study.

Avoided energy production from PET bottles

In the previous study it was assumed that recycled PET from the PET bottles end up in other products, and that these other products after use are incinerated at waste incineration plants with energy recovery. The PET bottles obtained a credit of 50% of this energy in spite of the above mentioned allocation procedure for the recycled PET. In the updated study, it is also assumed that the recycled PET ends up in other products, but after use it is assumed that these are deposited at landfills, hence the PET bottles obtain no energy credit. This results in a higher total contribution of CO_2 emissions for the updated study.

A.7.3 Sulphur dioxide

As can be seen from table A.6 the net emissions of SO_2 are significantly lower in the updated study (190 gram) than in the previous study (760 gram), corresponding to a reduction of approximately 75% of the net SO_2 emissions in the previous study.

The processes with the main significance for the difference of the SO_2 emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net SO_2 emissions in the previous study (*i.e.* 760 gram).

The processes that cause the main differences are:

- Production of PET granulates (reduction of 9%)
- Production of PET bottles (increase of 3%)
- Washing and filling (reduction of 64%)
- Production of screw caps (reduction of 5%)
- Production of labels (reduction of 3%)
- Avoided emissions from waste incineration (increase of 6%)
- Avoided PET production (reduction of 4%)
- Avoided energy production from recycled PET (increase of 4%)

Production of PET granulate

The difference of SO_2 emissions from the production of PET granulate is due to use of other data sources and the energy production in this data source.

Production of PET bottles

The change is caused by the change in data sources. The previous study used data from Holmia in Denmark who produces the PET bottles for the Danish marked. The updated study uses average data from APME.

Washing and filling

As already mentioned in section A.7.2 the soft drink producers have shifted from heat produced by fuel oil to heat produced by natural gas. Fuel oil contains sulphur, which Danish natural gas does not, hence the emissions of SO_2 is reduced.

The remaining processes

The explanations for the remaining processes are given in section A.7.2 Carbon dioxide.

A.7.4 Nitrogen oxides

As can be seen from table A.6 the net emissions of NO_X are lower in the updated study (370 gram) than in the previous study (440 gram), corresponding to a reduction of approximately 16% of the net NO_x emissions in the previous study.

The processes with the main significance for the difference of the NO_x emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net NO_x emissions in the previous study (*i.e.* 440 gram).

The processes that cause the main differences are:

- Production of PET granulates (increase of 7%)
- Washing and filling (reduction of 18%)
- Avoided emissions from waste incineration (increase of 5%)
- Avoided PET production (reduction of 5%)
- Avoided energy production from recycled PET (increase of 3%)

The explanations are given in section A.7.2 and 7.3.

A.7.5 Volatile organic compounds

As can be seen from table A.6 the net emissions of VOCs are lower in the updated study (190 gram) than in the previous study (230 gram), corresponding to a reduction of approximately 17% of the net VOC emissions in the previous study.

The processes with the main significance for the difference of the VOC emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net VOC emissions in the previous study (*i.e.* 190 gram).

The processes that cause the main differences are:

- Production of PET granulates (increase of 42)
- Washing and filling (reduction of 33%)
- Production of labels (reduction of 4%)
- Avoided emissions from waste incineration (increase of 5%)
- Avoided PET production (reduction of 22%)

The explanations are given in section A.7.2 and 7.3.

A.8 . Disposable PET bottles

The overall conclusions regarding disposable PET bottles of 50 cl and 150 cl are the same (although the differences in percentages are not always exactly the same). The main difference between the 50 cl and 150 cl is that the differences regarding the screw caps have bigger significance for the 50 cl bottles as 3 times as many screw caps are used per 1000 litres of soft drink. Hence, the 150 cl bottles will be used as an illustration in this chapter.

A.8.1 Results of the comparison

The total emissions of CO_2, SO_2, NO_x and VOCs in the previous and updated study for 150 cl disposable PET bottles are shown in table A.7 per 1000 litres of soft drink. The emissions are shown as the net amounts (*i.e.* the total contribution minus the avoided emissions).

Table A.7

Total emissions of CO_2, SO_2, NO_x and VOCs from the previous and updated study for 150 cl disposable PET bottles. Emissions per 1000 litres of soft drink. The results are rounded.

	Previous study	Updated study
CO_2 (kg)	≈ 250 kg	≈ 150 kg
SO_2 (gram)	≈ 2490 g	≈ 1010 g
NO_x (gram)	≈ 1020 g	≈ 870 g
NO_2 (gram)		
VOCs (gram)	≈ 930 g	NMVOC ≈ 66 g VOC ≈ 743 g Other specified VOC ≈ 0 g Total VOCs ≈ 810 g

A.8.2 Carbon dioxide

The total emissions of CO_2 are lower in the updated study (150 kg) than in the previous study (250 kg), corresponding to a reduction of approximately 40% of the net CO_2 emissions in the previous study.

The processes with the main significance for the difference are mentioned below. Some of the processes have an lower contribution of CO_2 in the updated study, and some higher contribution. The percentages given below are related to the net CO_2 emissions in the previous study (*i.e.* 250 kg).

The processes that cause the main differences are:

- Production of PET granulates (reduction of 35%)
- Production of PET bottles (increase of 19%)
- Filling (reduction of 3%)
- Distribution (increase of 7%)
- Transport, sum of other than distribution (reduction of 4%)
- Production of screw caps (reduction of 4%)
- Production of cardboard boxes (reduction of 55%)
- Avoided emissions from waste incineration (increase of 28%)
- Avoided PET production (reduction of 11%)
- Avoided energy production from recycled PET (increase of 18%)

In general, the explanations for the differences are the same as for refillable PET bottles, please see chapter A.7. However, it should be remarked that:

Production of cardboard boxes etc.

There are significant difference in the contribution of CO_2 from the production of cardboard boxes and trays when comparing the previous and updated study. The secondary packaging for the disposable bottles has been specified in the updating, and the total weight of the used cardboard per 1000 cl soft drink is reduced remarkable (with approximately 85% of the weight in the previous study). This is a significant improvement, as the weight of the secondary packaging in the previous study were based on assumptions only.

Furthermore, the data sources for producing cardboard, fibres etc. are improved.

Filling

The energy for filling the disposable 150 PET bottles has changed. In the previous study it was estimated on the basis of refillable PET bottles due to lack of data. This resulted in a consumption of electricity of 84 MJ per 1.000 litres of soft drink. In the updating, the energy consumption for this process are 57.6 MJ electricity and 60 MJ heat (as natural gas) per 1.000 litres of soft drink. This results in a slightly reduction of the CO_2 emissions.

Avoided emissions from waste incineration

It can be added to the explanation in chapter A.7, that the produced energy for disposable bottles is dominated by the incineration of cardboard boxes. As described above, the weight of cardboard for secondary packaging has been reduced significantly, hence, the energy from incineration and the avoided emissions are reduced accordingly. In the updating, the incineration of PET provides approximately the same amount of energy as incineration of cardboard and corrugated board.

A.8.3 Sulphur dioxide

As can be seen from table A.7 the net emissions of SO_2 are significantly lower in the updated study (1010 gram) than in the previous study (2490 gram), corresponding to a reduction of approximately 60% of the net SO_2 emissions in the previous study.

The processes with the main significance for the difference of the SO_2 emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net SO_2 emissions in the previous study (*i.e.* 2490 gram).

The processes that cause the main differences are:

- Production of PET granulates (reduction of 23%)
- Production of PET bottles (increase of 18%)
- Filling (reduction of 3%)
- Production of cardboard boxes (reduction of 63%)
- Avoided emissions from waste incineration (increase of 14%)
- Avoided PET production (reduction of 11%)

The remaining processes

The explanations for the differences are given in chapter A.7 and section A.8.2 Carbon dioxide.

A.8.4 Nitrogen oxides

As can be seen from table A.7 the net emissions of NO_X are lower in the updated study (870 gram) than in the previous study (1020 gram), corresponding to a reduction of approximately 14% of the net NO_x emissions in the previous study.

The processes with the main significance for the difference of the NO_x emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net NO_x emissions in the previous study (*i.e.* 1020 gram).

The processes that cause the main differences are:

- Production of PET granulates (increase of 7%)
- Production of PET bottles (increase of 16%)
- Filling (reduction of 2%)
- Distribution (increase of 14%)
- Transport, total (other than distribution) (decrease of 14%)
- Avoided emissions from waste incineration (increase of 20%)
- Avoided PET production (reduction of 23%)
- Avoided energy production from recycled PET (increase of 15%)

The explanations are given in chapter A.7 and section A.7.2.

A.8.5 Volatile organic compounds

As can be seen from table A.7 the net emissions of VOCs are slightly lower in the updated study (810 gram) than in the previous study (930 gram), corresponding to a reduction of approximately 13% of the net VOC emissions in the previous study.

The processes with the main significance for the difference of the VOC emissions are in general the same as for the CO_2 emissions with a few exceptions. They are all mentioned below. The percentages given below are related to the net VOC emissions in the previous study (*i.e.* 930 gram).

The processes that cause the main differences are:

- Production of PET granulate (increase of 81%)
- Production of PET bottles (increase of 4%)
- Distribution (increase of 6%)
- Transport, sum of other than distribution (reduction of 7%)
- Production of cardboard boxes (reduction of 48%)
- Avoided PET production (reduction of 49%)

The explanations are given in chapter A.7 and section A.8.2.

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Annex B:

Results based on the beverage consumption in 1996

Introduction

This annex includes characterisation, normalisation, and weighting results for all packaging systems using the annual consumption of beer and soft drinks in 1996.

Normalisation: 33 cl refillable green glass (base case)

Functional unit: 120.9 litres of beer (annual -96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	1,1E-01	1,5E-03	1,1E-01	3,7E-04	4,9E-06	3,7E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,2E-02	-2,3E-04	1,1E-02	5,8E-04	-1,2E-05	5,7E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	9,0E-02	8,4E-04	9,0E-02	7,2E-04	6,8E-06	7,3E-04
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	2,2E+01	-8,8E-01	2,1E+01	2,5E-03	-1,0E-04	2,4E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1350000*	7,7E+03	-3,5E+02	7,3E+03	5,7E-03	-2,6E-04	5,4E-03
Hazardous waste	g/pers/year	*20700*	6,7E+02	-4,6E+01	6,3E+02	3,3E-02	-2,2E-03	3,0E-02
Slag and ashes	g/pers/year	*320000*	2,6E+03	-2,0E-02	2,6E+03	7,3E-03	-5,7E-08	7,3E-03
Nuclear waste	g/pers/year	*159*	1,4E+00	1,2E-03	1,4E+00	8,5E-03	7,5E-06	8,5E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*590000*	1,5E+03	-1,6E+02	1,3E+03	2,5E-03	-2,7E-04	2,2E-03
Coal	g/pers/year	*931400*	6,6E+03	-4,8E+01	6,6E+03	7,1E-03	-5,1E-05	7,1E-03
Brown coal	g/pers/year	*250000*	7,5E+01	-2,9E+00	7,2E+01	3,0E-04	-1,2E-05	2,9E-04
Natural gas	g/pers/year	*310000*	1,8E+03	-1,3E+02	1,7E+03	6,0E-03	-4,0E-04	5,5E-03
Aluminium (Al)	g/pers/year	*3100*	8,1E+00	-5,9E-05	8,1E+00	2,4E-03	-1,7E-08	2,4E-03
Iron (Fe)	g/pers/year	*100000*	6,6E+02	-6,0E-05	6,6E+02	6,6E-03	-6,0E-10	6,6E-03
Manganese (Mn)	g/pers/year	*1800*	4,7E-05	-3,4E-07	4,6E-05	2,6E-08	-1,9E-10	2,6E-08
Tin (Sn)	g/pers/year	*40*	1,6E+00	0,0E+00	1,6E+00	4,0E-02	0,0E+00	4,0E-02

Weighting: 33 cl refillable green glass (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	3,7E-04	4,9E-06	3,7E-04	4,4E-04	5,9E-06	4,5E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	5,8E-04	-1,2E-05	5,7E-04	7,0E-04	-1,4E-05	6,9E-04
Acidification (AP)	PET/PE	*1,3*	7,2E-04	6,8E-06	7,3E-04	9,4E-04	8,8E-06	9,5E-04
Global warming (GWP)	PET/PE	*1,3*	2,5E-03	-1,0E-04	2,4E-03	3,3E-03	-1,3E-04	3,2E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	PET/PE	*1,1*	5,7E-03	-2,6E-04	5,4E-03	6,2E-03	-2,8E-04	6,0E-03
Hazardous waste	PET/PE	*1,1*	3,3E-02	-2,2E-03	3,0E-02	3,6E-02	-2,4E-03	3,3E-02
Slag and ashes	PET/PE	*1,1*	7,3E-03	-5,7E-08	7,3E-03	8,0E-03	-6,3E-08	8,0E-03
Nuclear waste	PET/PE	*1,1*	8,5E-03	7,5E-06	8,5E-03	9,4E-03	8,2E-06	9,4E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	2,5E-03	-2,7E-04	2,2E-03	5,7E-05	-6,2E-06	5,1E-05
Coal	l/year	*0.0058*	7,1E-03	-5,1E-05	7,1E-03	4,1E-05	-3,0E-07	4,1E-05
Brown coal	l/year	*0,0026*	3,0E-04	-1,2E-05	2,9E-04	7,8E-07	-3,0E-08	7,5E-07
Natural gas	l/year	*0,016*	6,0E-03	-4,0E-04	5,5E-03	9,5E-05	-6,5E-06	8,9E-05
Aluminium (Al)	l/year	*0,0051*	2,4E-03	-1,7E-08	2,4E-03	1,2E-05	-8,8E-11	1,2E-05
Iron (Fe)	l/year	*0,0085*	6,6E-03	-6,0E-10	6,6E-03	5,6E-05	-5,1E-12	5,6E-05
Manganese (Mn)	l/year	*0,012*	2,6E-08	-1,9E-10	2,6E-08	3,1E-10	-2,3E-12	3,1E-10
Tin (Sn)	l/year	*0,037*	4,0E-02	0,0E+00	4,0E-02	1,5E-03	0,0E+00	1,5E-03

Normalisation: 25 cl refillable white glass (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	9,7E-02	-1,6E-03	9,5E-02	3,3E-04	-5,3E-06	3,2E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,1E-02	-6,7E-04	1,1E-02	5,7E-04	-3,4E-05	5,4E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	8,3E-02	-1,7E-03	8,2E-02	6,7E-04	-1,4E-05	6,6E-04
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	1,9E+01	-1,2E+00	1,8E+01	2,2E-03	-1,4E-04	2,1E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	6,6E+03	-3,8E+02	6,2E+03	4,9E-03	-2,8E-04	4,6E-03
Hazardous waste	g/pers/year	*20700*	5,6E+02	-4,6E+01	5,2E+02	2,7E-02	-2,2E-03	2,5E-02
Slag and ashes	g/pers/year	*3,20E+05*	2,2E+03	-8,6E-01	2,2E+03	6,3E-03	-2,5E-06	6,3E-03
Nuclear waste	g/pers/year	*159*	1,1E+00	1,1E+00	2,2E+00	7,0E-03	7,0E-03	1,4E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	1,3E+03	-2,1E+02	1,1E+03	2,2E-03	-3,6E-04	1,9E-03
Coal	g/pers/year	*9,31E+05*	5,8E+03	-1,1E+02	5,7E+03	6,2E-03	-1,1E-04	6,1E-03
Brown coal	g/pers/year	*2,50E+05*	6,5E+01	-4,2E+00	6,1E+01	2,6E-04	-1,7E-05	2,4E-04
Natural gas	g/pers/year	*3,10E+05*	1,6E+03	-1,3E+02	1,4E+03	5,1E-03	-4,2E-04	4,6E-03
Aluminium (Al)	g/pers/year	*3100*	1,4E-02	-1,2E-04	1,3E-02	4,0E-06	-3,7E-08	3,9E-06
Iron (Fe)	g/pers/year	*1,00E+05*	6,7E+02	-1,3E-04	6,7E+02	6,7E-03	-1,3E-09	6,7E-03
Manganese (Mn)	g/pers/year	*1800*	4,0E-05	-7,4E-07	4,0E-05	2,2E-08	-4,1E-10	2,2E-08
Tin (Sn)	g/pers/year	*40*	1,6E+00	0,0E+00	1,6E+00	4,1E-02	0,0E+00	4,1E-02

Weighting:25 cl refillable white glass (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	3,3E-04	-5,3E-06	3,2E-04	3,9E-04	-6,3E-06	3,8E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	5,7E-04	-3,4E-05	5,4E-04	6,8E-04	-4,0E-05	6,4E-04
Acidification (AP)	PET/PE	*1,3*	6,7E-04	-1,4E-05	6,6E-04	8,7E-04	-1,8E-05	8,6E-04
Global warming (GWP)	PET/PE	*1,3*	2,2E-03	-1,4E-04	2,1E-03	2,9E-03	-1,9E-04	2,7E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	PET/PE	*1,1*	4,9E-03	-2,8E-04	4,6E-03	5,4E-03	-3,1E-04	5,0E-03
Hazardous waste	PET/PE	*1,1*	2,7E-02	-2,2E-03	2,5E-02	3,0E-02	-2,4E-03	2,8E-02
Slag and ashes	PET/PE	*1,1*	6,3E-03	-2,5E-06	6,3E-03	6,9E-03	-2,7E-06	6,9E-03
Nuclear waste	PET/PE	*1,1*	7,0E-03	7,0E-03	1,4E-02	7,7E-03	7,7E-03	1,5E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	2,2E-03	-3,6E-04	1,9E-03	5,1E-05	-8,3E-06	4,3E-05
Coal	l/year	*0,0058*	6,2E-03	-1,1E-04	6,1E-03	3,6E-05	-6,6E-07	3,5E-05
Brown coal	l/year	*0,0026*	2,6E-04	-1,7E-05	2,4E-04	6,8E-07	-4,4E-08	6,3E-07
Natural gas	l/year	*0,016*	5,1E-03	-4,2E-04	4,6E-03	8,1E-05	-6,8E-06	7,4E-05
Aluminium (Al)	l/year	*0,0051*	4,0E-06	-3,7E-08	3,9E-06	2,0E-08	-1,9E-10	2,0E-08
Iron (Fe)	l/year	*0,0085*	6,7E-03	-1,3E-09	6,7E-03	5,7E-05	-1,1E-11	5,7E-05
Manganese (Mn)	l/year	*0,012*	2,2E-08	-4,1E-10	2,2E-08	2,7E-10	-4,9E-12	2,6E-10
Tin (Sn)	l/year	*0,037*	4,1E-02	0,0E+00	4,1E-02	1,5E-03	0,0E+00	1,5E-03

Normalisation: 33 cl disposable green glass (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	3,0E-01	2,3E-02	3,2E-01	1,0E-03	7,7E-05	1,1E-03
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,8E-02	9,4E-04	1,9E-02	9,0E-04	4,7E-05	9,4E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	2,8E-01	1,1E-02	2,9E-01	2,2E-03	9,1E-05	2,3E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	4,8E+01	-2,2E+00	4,6E+01	5,5E-03	-2,6E-04	5,3E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	g/pers/year	*1,35E+06*	9,9E+03	-1,3E+03	8,6E+03	7,3E-03	-9,6E-04	6,3E-03
Hazardous waste	g/pers/year	*20700*	3,2E+02	-1,8E+02	1,3E+02	1,5E-02	-8,8E-03	6,4E-03
Slag and ashes	g/pers/year	*3,20E+05*	6,7E+03	5,1E+00	6,7E+03	1,9E-02	1,5E-05	1,9E-02
Nuclear waste	g/pers/year	*159*	1,1E+00	3,1E-02	1,2E+00	7,1E-03	1,9E-04	7,3E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	2,3E+03	6,6E+01	2,4E+03	3,9E-03	1,1E-04	4,0E-03
Coal	g/pers/year	*9,31E+05*	1,3E+04	-3,7E+01	1,3E+04	1,4E-02	-4,0E-05	1,4E-02
Brown coal	g/pers/year	*2,50E+05*	1,4E+02	1,2E+00	1,4E+02	5,6E-04	5,0E-06	5,7E-04
Natural gas	g/pers/year	*3,10E+05*	8,1E+02	-5,1E+02	3,0E+02	2,6E-03	-1,7E-03	9,5E-04
Aluminium (Al)	g/pers/year	*3100*	2,0E+00	7,2E-06	2,0E+00	6,0E-04	2,1E-09	6,0E-04
Iron (Fe)	g/pers/year	*1,00E+05*	7,0E+02	-4,0E-05	7,0E+02	7,0E-03	-4,0E-10	7,0E-03
Manganese (Mn)	g/pers/year	*1800*	9,4E-05	-1,7E-07	9,4E-05	5,2E-08	-9,7E-11	5,2E-08
Tin (Sn)	g/pers/year	*40*	1,7E+00	0,0E+00	1,7E+00	4,2E-02	0,0E+00	4,2E-02

Weighting: 33 cl disposable green glass (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Nutrient enrichment (NP)	PET/PE	*1,2*	1,0E-03	7,7E-05	1,1E-03	1,2E-03	9,3E-05	1,3E-03
Photochemical ozone formation (POCP)	PET/PE	*1,2*	9,0E-04	4,7E-05	9,4E-04	1,1E-03	5,6E-05	1,1E-03
Acidification (AP)	PET/PE	*1,3*	2,2E-03	9,1E-05	2,3E-03	2,9E-03	1,2E-04	3,0E-03
Global warming (GWP)	PET/PE	*1,3*	5,5E-03	-2,6E-04	5,3E-03	7,2E-03	-3,4E-04	6,8E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	PET/PE	*1,1*	7,3E-03	-9,6E-04	6,3E-03	8,0E-03	-1,1E-03	7,0E-03
Hazardous waste	PET/PE	*1,1*	1,5E-02	-8,8E-03	6,4E-03	1,7E-02	-9,7E-03	7,1E-03
Slag and ashes	PET/PE	*1,1*	1,9E-02	1,5E-05	1,9E-02	2,1E-02	1,6E-05	2,1E-02
Nuclear waste	PET/PE	*1,1*	7,1E-03	1,9E-04	7,3E-03	7,8E-03	2,1E-04	8,0E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	3,9E-03	1,1E-04	4,0E-03	9,0E-05	2,6E-06	9,3E-05
Coal	l/year	*0,0058*	1,4E-02	-4,0E-05	1,4E-02	8,2E-05	-2,3E-07	8,2E-05
Brown coal	l/year	*0,0026*	5,6E-04	5,0E-06	5,7E-04	1,5E-06	1,3E-08	1,5E-06
Natural gas	l/year	*0,016*	2,6E-03	-1,7E-03	9,5E-04	4,2E-05	-2,6E-05	1,5E-05
Aluminium (Al)	l/year	*0,0051*	6,0E-04	2,1E-09	6,0E-04	3,0E-06	1,1E-11	3,0E-06
Iron (Fe)	l/year	*0,0085*	7,0E-03	-4,0E-10	7,0E-03	5,9E-05	-3,4E-12	5,9E-05
Manganese (Mn)	l/year	*0,012*	5,2E-08	-9,7E-11	5,2E-08	6,3E-10	-1,2E-12	6,3E-10
Tin (Sn)	l/year	*0,037*	4,2E-02	0,0E+00	4,2E-02	1,6E-03	0,0E+00	1,6E-03

Normalisation: 33 cl disposable white glass (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	2,2E-01	-2,0E-02	2,0E-01	7,5E-04	-6,6E-05	6,8E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,8E-02	-4,9E-03	1,3E-02	9,1E-04	-2,5E-04	6,6E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	2,2E-01	-2,3E-02	2,0E-01	1,8E-03	-1,8E-04	1,6E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	3,8E+01	-6,7E+00	3,2E+01	4,4E-03	-7,7E-04	3,6E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	g/pers/year	*1,35E+06*	6,2E+03	-1,6E+03	4,6E+03	4,6E-03	-1,2E-03	3,4E-03
Hazardous waste	g/pers/year	*20700*	2,3E+02	-1,5E+02	8,0E+01	1,1E-02	-7,3E-03	3,9E-03
Slag and ashes	g/pers/year	*3,20E+05*	4,8E+03	-3,3E+00	4,8E+03	1,4E-02	-9,4E-06	1,4E-02
Nuclear waste	g/pers/year	*159*	8,3E-01	9,0E-03	8,4E-01	5,2E-03	5,6E-05	5,3E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	2,3E+03	-6,9E+02	1,6E+03	3,9E-03	-1,2E-03	2,8E-03
Coal	g/pers/year	*9,31E+05*	8,3E+03	-6,0E+02	7,7E+03	9,0E-03	-6,4E-04	8,3E-03
Brown coal	g/pers/year	*2,50E+05*	1,0E+02	-1,5E+01	8,7E+01	4,1E-04	-5,9E-05	3,5E-04
Natural gas	g/pers/year	*3,10E+05*	7,2E+02	-5,1E+02	2,1E+02	2,3E-03	-1,6E-03	6,9E-04
Aluminium (Al)	g/pers/year	*3100*	2,1E-02	-6,5E-04	2,1E-02	6,3E-06	-1,9E-07	6,1E-06
Iron (Fe)	g/pers/year	*1,00E+05*	5,1E+02	-6,7E-04	5,1E+02	5,1E-03	-6,7E-09	5,1E-03
Manganese (Mn)	g/pers/year	*1800*	5,9E-05	-3,9E-06	5,5E-05	3,3E-08	-2,2E-09	3,1E-08
Tin (Sn)	g/pers/year	*40*	1,2E+00	0,0E+00	1,2E+00	3,1E-02	0,0E+00	3,1E-02

Weighting: 33 cl disposable white glass (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	7,5E-04	-6,6E-05	6,8E-04	8,9E-04	-7,9E-05	8,2E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	9,1E-04	-2,5E-04	6,6E-04	1,1E-03	-2,9E-04	7,9E-04
Acidification (AP)	PET/PE	*1,3*	1,8E-03	-1,8E-04	1,6E-03	2,3E-03	-2,4E-04	2,1E-03
Global warming (GWP)	PET/PE	*1,3*	4,4E-03	-7,7E-04	3,6E-03	5,7E-03	-1,0E-03	4,7E-03

Waste	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	4,6E-03	-1,2E-03	3,4E-03	5,1E-03	-1,3E-03	3,8E-03
Hazardous waste	PET/PE	*1,1*	1,1E-02	-7,3E-03	3,9E-03	1,2E-02	-8,0E-03	4,3E-03
Slag and ashes	PET/PE	*1,1*	1,4E-02	-9,4E-06	1,4E-02	1,5E-02	-1,0E-05	1,5E-02
Nuclear waste	PET/PE	*1,1*	5,2E-03	5,6E-05	5,3E-03	5,7E-03	6,2E-05	5,8E-03

Resource consumption (RR 90)								
Non-renewable								
Oil	1/year	*0,023*	3,9E-03	-1,2E-03	2,8E-03	9,1E-05	-2,7E-05	6,4E-05
Coal	1/year	*0.0058*	9,0E-03	-6,4E-04	8,3E-03	5,2E-05	-3,7E-06	4,8E-05
Brown coal	1/year	*0.0026*	4,1E-04	-5,9E-05	3,5E-04	1,1E-06	-1,5E-07	9,1E-07
Natural gas	1/year	*0,016*	2,3E-03	-1,6E-03	6,9E-04	3,7E-05	-2,6E-05	1,1E-05
Aluminium (Al)	1/year	*0.0051*	6,3E-06	-1,9E-07	6,1E-06	3,2E-08	-9,8E-10	3,1E-08
Iron (Fe)	1/year	*0.0085*	5,1E-03	-6,7E-09	5,1E-03	4,3E-05	-5,7E-11	4,3E-05
Manganese (Mn)	1/year	*0,012*	3,3E-08	-2,2E-09	3,1E-08	4,0E-10	-2,6E-11	3,7E-10
Tin (Sn)	1/year	*0,037*	3,1E-02	0,0E+00	3,1E-02	1,1E-03	0,0E+00	1,1E-03

Normalisation: 33 cl aluminium can (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	2,1E-01	-3,0E-03	2,1E-01	7,0E-04	-1,0E-05	6,9E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,8E-02	-2,2E-03	1,6E-02	9,2E-04	-1,1E-04	8,1E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	2,1E-01	-3,3E-03	2,1E-01	1,7E-03	-2,7E-05	1,7E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	4,9E+01	-4,2E+00	4,5E+01	5,6E-03	-4,8E-04	5,1E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	1,2E+04	-1,5E+03	1,1E+04	9,2E-03	-1,1E-03	8,1E-03
Hazardous waste	g/pers/year	*20700*	8,5E+02	-1,8E+02	6,8E+02	4,1E-02	-8,6E-03	3,3E-02
Slag and ashes	g/pers/year	*3,20E+05*	1,8E+03	2,4E+00	1,8E+03	5,3E-03	6,8E-06	5,3E-03
Nuclear waste	g/pers/year	*159*	2,0E+00	2,1E-02	2,0E+00	1,3E-02	1,3E-04	1,3E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	3,3E+03	-6,6E+02	2,7E+03	5,7E-03	-1,1E-03	4,6E-03
Coal	g/pers/year	*9,31E+05*	2,1E+04	-1,3E+02	2,1E+04	2,2E-02	-1,4E-04	2,2E-02
Brown coal	g/pers/year	*2,50E+05*	2,1E+02	-1,1E+01	1,9E+02	8,2E-04	-4,5E-05	7,8E-04
Natural gas	g/pers/year	*3,10E+05*	2,0E+03	-5,1E+02	1,5E+03	6,4E-03	-1,7E-03	4,7E-03
Aluminium (Al)	g/pers/year	*3100*	7,6E+02	-1,4E-04	7,6E+02	2,2E-01	-4,1E-08	2,2E-01
Iron (Fe)	g/pers/year	*1,00E+05*	2,7E-02	-1,5E-04	2,7E-02	2,7E-07	-1,5E-09	2,7E-07
Manganese (Mn)	g/pers/year	*1800*	1,1E+01	-8,3E-07	1,1E+01	6,3E-03	-4,6E-10	6,3E-03

Weighting: 33 cl aluminium can (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	7,0E-04	-1,0E-05	6,9E-04	8,4E-04	-1,2E-05	8,3E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	9,2E-04	-1,1E-04	8,1E-04	1,1E-03	-1,3E-04	9,7E-04
Acidification (AP)	PET/PE	*1,3*	1,7E-03	-2,7E-05	1,7E-03	2,2E-03	-3,5E-05	2,2E-03
Global warming (GWP)	PET/PE	*1,3*	5,6E-03	-4,8E-04	5,1E-03	7,3E-03	-6,3E-04	6,7E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	9,2E-03	-1,1E-03	8,1E-03	1,0E-02	-1,2E-03	8,9E-03
Hazardous waste	PET/PE	*1,1*	4,1E-02	-8,6E-03	3,3E-02	4,5E-02	-9,5E-03	3,6E-02
Slag and ashes	PET/PE	*1,1*	5,3E-03	6,8E-06	5,3E-03	5,8E-03	7,5E-06	5,8E-03
Nuclear waste	PET/PE	*1,1*	1,3E-02	1,3E-04	1,3E-02	1,4E-02	1,4E-04	1,4E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	5,7E-03	-1,1E-03	4,6E-03	1,3E-04	-2,6E-05	1,0E-04
Coal	l/year	*0,0058*	2,2E-02	-1,4E-04	2,2E-02	1,3E-04	-7,9E-07	1,3E-04
Brown coal	l/year	*0.0026*	8,2E-04	-4,5E-05	7,8E-04	2,1E-06	-1,2E-07	2,0E-06
Natural gas	l/year	*0,016*	6,4E-03	-1,7E-03	4,7E-03	1,0E-04	-2,6E-05	7,5E-05
Aluminium (Al)	l/year	*0,0051*	2,2E-01	-4,1E-08	2,2E-01	1,1E-03	-2,1E-10	1,1E-03
Iron (Fe)	l/year	*0,0085*	2,7E-07	-1,5E-09	2,7E-07	2,3E-09	-1,2E-11	2,3E-09
Manganese (Mn)	l/year	*0,012*	6,3E-03	-4,6E-10	6,3E-03	7,6E-05	-5,5E-12	7,6E-05

Normalisation: 33 cl aluminium can (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	1,6E-01	-2,3E-03	1,6E-01	5,4E-04	-7,8E-06	5,3E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,4E-02	-1,7E-03	1,2E-02	7,0E-04	-8,3E-05	6,2E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	1,6E-01	-2,6E-03	1,6E-01	1,3E-03	-2,1E-05	1,3E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	3,8E+01	-3,2E+00	3,4E+01	4,3E-03	-3,7E-04	3,9E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	g/pers/year	*1,35E+06*	9,5E+03	-1,1E+03	8,4E+03	7,1E-03	-8,3E-04	6,2E-03
Hazardous waste	g/pers/year	*20700*	6,6E+02	-1,4E+02	5,2E+02	3,2E-02	-6,6E-03	2,5E-02
Slag and ashes	g/pers/year	*3,20E+05*	1,4E+03	1,8E+00	1,4E+03	4,0E-03	5,2E-06	4,0E-03
Nuclear waste	g/pers/year	*159*	1,5E+00	1,6E-02	1,6E+00	9,7E-03	1,0E-04	9,8E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	2,6E+03	-5,1E+02	2,1E+03	4,4E-03	-8,6E-04	3,5E-03
Coal	g/pers/year	*9,31E+05*	1,6E+04	-9,7E+01	1,6E+04	1,7E-02	-1,0E-04	1,7E-02
Brown coal	g/pers/year	*2,50E+05*	1,6E+02	-8,6E+00	1,5E+02	6,3E-04	-3,4E-05	6,0E-04
Natural gas	g/pers/year	*3,10E+05*	1,5E+03	-3,9E+02	1,1E+03	4,9E-03	-1,3E-03	3,6E-03
Aluminium (Al)	g/pers/year	*3100*	5,8E+02	-1,1E-04	5,8E+02	1,7E-01	-3,2E-08	1,7E-01
Iron (Fe)	g/pers/year	*1,00E+05*	2,1E-02	-1,1E-04	2,1E-02	2,1E-07	-1,1E-09	2,1E-07
Manganese (Mn)	g/pers/year	*1800*	8,8E+00	-6,3E-07	8,8E+00	4,9E-03	-3,5E-10	4,9E-03

Weighting: 33 cl aluminium can (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	5,4E-04	-7,8E-06	5,3E-04	6,4E-04	-9,4E-06	6,3E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	7,0E-04	-8,3E-05	6,2E-04	8,4E-04	-9,9E-05	7,4E-04
Acidification (AP)	PET/PE	*1,3*	1,3E-03	-2,1E-05	1,3E-03	1,7E-03	-2,7E-05	1,7E-03
Global warming (GWP)	PET/PE	*1,3*	4,3E-03	-3,7E-04	3,9E-03	5,6E-03	-4,8E-04	5,1E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	PET/PE	*1,1*	7,1E-03	-8,3E-04	6,2E-03	7,8E-03	-9,2E-04	6,9E-03
Hazardous waste	PET/PE	*1,1*	3,2E-02	-6,6E-03	2,5E-02	3,5E-02	-7,3E-03	2,8E-02
Slag and ashes	PET/PE	*1,1*	4,0E-03	5,2E-06	4,0E-03	4,4E-03	5,8E-06	4,4E-03
Nuclear waste	PET/PE	*1,1*	9,7E-03	1,0E-04	9,8E-03	1,1E-02	1,1E-04	1,1E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0.023*	4,4E-03	-8,6E-04	3,5E-03	1,0E-04	-2,0E-05	8,0E-05
Coal	l/year	*0.0058*	1,7E-02	-1,0E-04	1,7E-02	9,9E-05	-6,0E-07	9,9E-05
Brown coal	l/year	*0.0026*	6,3E-04	-3,4E-05	6,0E-04	1,6E-06	-9,0E-08	1,6E-06
Natural gas	l/year	*0.016*	4,9E-03	-1,3E-03	3,6E-03	7,8E-05	-2,0E-05	5,8E-05
Aluminium (Al)	l/year	*0.0051*	1,7E-01	-3,2E-08	1,7E-01	8,7E-04	-1,6E-10	8,7E-04
Iron (Fe)	l/year	*0.0085*	2,1E-07	-1,1E-09	2,1E-07	1,8E-09	-9,5E-12	1,8E-09
Manganese (Mn)	l/year	*0.012*	4,9E-03	-3,5E-10	4,9E-03	5,8E-05	-4,2E-12	5,8E-05

Normalisation: 50 cl aluminium can (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	**Normalisation reference**		**Characterisation results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	1,7E-01	-2,5E-03	1,7E-01	5,7E-04	-8,5E-06	5,6E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,6E-02	-1,7E-03	1,4E-02	7,8E-04	-8,4E-05	7,0E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	1,7E-01	-2,7E-03	1,7E-01	1,4E-03	-2,2E-05	1,3E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	3,9E+01	-3,2E+00	3,6E+01	4,5E-03	-3,7E-04	4,1E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	9,9E+03	-1,1E+03	8,7E+03	7,3E-03	-8,3E-04	6,5E-03
Hazardous waste	g/pers/year	*20700*	6,9E+02	-1,4E+02	5,6E+02	3,3E-02	-6,6E-03	2,7E-02
Slag and ashes	g/pers/year	*3,20E+05*	1,5E+03	1,6E+00	1,5E+03	4,4E-03	4,6E-06	4,4E-03
Nuclear waste	g/pers/year	*159*	1,8E+00	1,5E-02	1,8E+00	1,1E-02	9,5E-05	1,1E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	2,9E+03	-5,1E+02	2,3E+03	4,8E-03	-8,7E-04	4,0E-03
Coal	g/pers/year	*9,31E+05*	1,6E+04	-1,1E+02	1,6E+04	1,7E-02	-1,2E-04	1,7E-02
Brown coal	g/pers/year	*2,50E+05*	1,6E+02	-8,8E+00	1,6E+02	6,6E-04	-3,5E-05	6,2E-04
Natural gas	g/pers/year	*3,10E+05*	1,6E+03	-3,9E+02	1,2E+03	5,2E-03	-1,3E-03	4,0E-03
Aluminium (Al)	g/pers/year	*3100*	5,9E+02	-1,2E-04	5,9E+02	1,7E-01	-3,5E-08	1,7E-01
Iron (Fe)	g/pers/year	*1,00E+05*	2,1E-02	-1,2E-04	2,1E-02	2,1E-07	-1,2E-09	2,1E-07
Manganese (Mn)	g/pers/year	*1800*	8,8E+00	-7,1E-07	8,8E+00	4,9E-03	-3,9E-10	4,9E-03

Weighting: 50 cl aluminium can (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	5,7E-04	-8,5E-06	5,6E-04	6,8E-04	-1,0E-05	6,7E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	7,8E-04	-8,4E-05	7,0E-04	9,4E-04	-1,0E-04	8,4E-04
Acidification (AP)	PET/PE	*1,3*	1,4E-03	-2,2E-05	1,3E-03	1,8E-03	-2,9E-05	1,7E-03
Global warming (GWP)	PET/PE	*1,3*	4,5E-03	-3,7E-04	4,1E-03	5,8E-03	-4,8E-04	5,3E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	PET/PE	*1,1*	7,3E-03	-8,3E-04	6,5E-03	8,0E-03	-9,1E-04	7,1E-03
Hazardous waste	PET/PE	*1,1*	3,3E-02	-6,6E-03	2,7E-02	3,7E-02	-7,2E-03	3,0E-02
Slag and ashes	PET/PE	*1,1*	4,4E-03	4,6E-06	4,4E-03	4,8E-03	5,0E-06	4,8E-03
Nuclear waste	PET/PE	*1,1*	1,1E-02	9,5E-05	1,1E-02	1,2E-02	1,0E-04	1,3E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	4,8E-03	-8,7E-04	4,0E-03	1,1E-04	-2,0E-05	9,1E-05
Coal	l/year	*0,0058*	1,7E-02	-1,2E-04	1,7E-02	1,0E-04	-6,7E-07	1,0E-04
Brown coal	l/year	*0,0026*	6,6E-04	-3,5E-05	6,2E-04	1,7E-06	-9,2E-08	1,6E-06
Natural gas	l/year	*0,016*	5,2E-03	-1,3E-03	4,0E-03	8,4E-05	-2,0E-05	6,4E-05
Aluminium (Al)	l/year	*0,0051*	1,7E-01	-3,5E-08	1,7E-01	8,8E-04	-1,8E-10	8,8E-04
Iron (Fe)	l/year	*0,0085*	2,1E-07	-1,2E-09	2,1E-07	1,8E-09	-1,1E-11	1,8E-09
Manganese (Mn)	l/year	*0,012*	4,9E-03	-3,9E-10	4,9E-03	5,9E-05	-4,7E-12	5,9E-05

Normalisation: 50 cl aluminium can (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	1,3E-01	-2,0E-03	1,3E-01	4,4E-04	-6,6E-06	4,3E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,2E-02	-1,3E-03	1,1E-02	6,0E-04	-6,4E-05	5,4E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	1,3E-01	-2,1E-03	1,3E-01	1,0E-03	-1,7E-05	1,0E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	3,0E+01	-2,5E+00	2,7E+01	3,4E-03	-2,9E-04	3,1E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	7,6E+03	-8,6E+02	6,7E+03	5,6E-03	-6,4E-04	5,0E-03
Hazardous waste	g/pers/year	*20700*	5,3E+02	-1,0E+02	4,3E+02	2,6E-02	-5,1E-03	2,1E-02
Slag and ashes	g/pers/year	*3,20E+05*	1,2E+03	1,2E+00	1,2E+03	3,4E-03	3,5E-06	3,4E-03
Nuclear waste	g/pers/year	*159*	1,4E+00	1,2E-02	1,4E+00	8,7E-03	7,3E-05	8,7E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	2,2E+03	-3,9E+02	1,8E+03	3,7E-03	-6,7E-04	3,0E-03
Coal	g/pers/year	*9,31E+05*	1,2E+04	-8,3E+01	1,2E+04	1,3E-02	-8,9E-05	1,3E-02
Brown coal	g/pers/year	*2,50E+05*	1,3E+02	-6,8E+00	1,2E+02	5,0E-04	-2,7E-05	4,8E-04
Natural gas	g/pers/year	*3,10E+05*	1,2E+03	-3,0E+02	9,5E+02	4,0E-03	-9,7E-04	3,1E-03
Aluminium (Al)	g/pers/year	*3100*	4,5E+02	-9,2E-05	4,5E+02	1,3E-01	-2,7E-08	1,3E-01
Iron (Fe)	g/pers/year	*1,00E+05*	1,6E-02	-9,6E-05	1,6E-02	1,6E-07	-9,6E-10	1,6E-07
Manganese (Mn)	g/pers/year	*1800*	6,8E+00	-5,4E-07	6,8E+00	3,8E-03	-3,0E-10	3,8E-03

Weighting: 50 cl aluminium can (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	4,4E-04	-6,6E-06	4,3E-04	5,2E-04	-7,9E-06	5,2E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	6,0E-04	-6,4E-05	5,4E-04	7,2E-04	-7,7E-05	6,4E-04
Acidification (AP)	PET/PE	*1,3*	1,0E-03	-1,7E-05	1,0E-03	1,4E-03	-2,2E-05	1,3E-03
Global warming (GWP)	PET/PE	*1,3*	3,4E-03	-2,9E-04	3,1E-03	4,5E-03	-3,7E-04	4,1E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	5,6E-03	-6,4E-04	5,0E-03	6,2E-03	-7,0E-04	5,5E-03
Hazardous waste	PET/PE	*1,1*	2,6E-02	-5,1E-03	2,1E-02	2,8E-02	-5,6E-03	2,3E-02
Slag and ashes	PET/PE	*1,1*	3,4E-03	3,5E-06	3,4E-03	3,7E-03	3,9E-06	3,7E-03
Nuclear waste	PET/PE	*1,1*	8,7E-03	7,3E-05	8,7E-03	9,5E-03	8,0E-05	9,6E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	3,7E-03	-6,7E-04	3,0E-03	8,5E-05	-1,5E-05	7,0E-05
Coal	l/year	*0,0058*	1,3E-02	-8,9E-05	1,3E-02	7,7E-05	-5,2E-07	7,6E-05
Brown coal	l/year	*0,0026*	5,0E-04	-2,7E-05	4,8E-04	1,3E-06	-7,0E-08	1,2E-06
Natural gas	l/year	*0,016*	4,0E-03	-9,7E-04	3,1E-03	6,4E-05	-1,6E-05	4,9E-05
Aluminium (Al)	l/year	*0,0051*	1,3E-01	-2,7E-08	1,3E-01	6,8E-04	-1,4E-10	6,8E-04
Iron (Fe)	l/year	*0,0085*	1,6E-07	-9,6E-10	1,6E-07	1,4E-09	-8,1E-12	1,4E-09
Manganese (Mn)	l/year	*0,012*	3,8E-03	-3,0E-10	3,8E-03	4,5E-05	-3,6E-12	4,5E-05

Normalisation: 33cl steel can (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	3,2E-01	-6,9E-02	2,5E-01	1,1E-03	-2,3E-04	8,5E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	3,0E-02	-9,6E-03	2,1E-02	1,5E-03	-4,8E-04	1,0E-03
Acidification (AP)	kg SO2-eq/pers/year	*124*	3,5E-01	-8,9E-02	2,6E-01	2,8E-03	-7,2E-04	2,1E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	8,4E+01	-2,9E+01	5,5E+01	9,6E-03	-3,3E-03	6,3E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	3,0E+04	-1,2E+04	1,8E+04	2,2E-02	-8,7E-03	1,4E-02
Hazardous waste	g/pers/year	*20700*	1,3E+03	-1,2E+02	1,2E+03	6,2E-02	-5,6E-03	5,6E-02
Slag and ashes	g/pers/year	*3,20E+05*	8,9E+02	3,3E+01	9,2E+02	2,5E-03	9,6E-05	2,6E-03
Nuclear waste	g/pers/year	*159*	2,0E+00	2,9E-01	2,3E+00	1,3E-02	1,8E-03	1,4E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	4,9E+03	-1,4E+03	3,5E+03	8,3E-03	-2,4E-03	5,9E-03
Coal	g/pers/year	*9,31E+05*	3,7E+04	-3,3E+03	3,3E+04	3,9E-02	-3,5E-03	3,6E-02
Brown coal	g/pers/year	*2,50E+05*	3,6E+02	-4,9E+01	3,1E+02	1,4E-03	-2,0E-04	1,2E-03
Natural gas	g/pers/year	*3,10E+05*	3,1E+03	-3,1E+02	2,8E+03	1,0E-02	-1,0E-03	9,0E-03
Aluminium (Al)	g/pers/year	*3100*	1,3E+03	-2,3E+02	1,1E+03	3,8E-01	-6,6E-02	3,1E-01
Iron (Fe)	g/pers/year	*1,00E+05*	1,0E+04	-9,3E+03	6,6E+02	1,0E-01	-9,3E-02	6,6E-03
Manganese (Mn)	g/pers/year	*1800*	2,6E-04	-2,3E-05	2,4E-04	1,5E-07	-1,3E-08	1,3E-07
Tin (Sn)	g/pers/year	*40*	2,4E+01	0,0E+00	2,4E+01	6,0E-01	0,0E+00	6,0E-01

Weighting: 33cl steel can (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	1,1E-03	-2,3E-04	8,5E-04	1,3E-03	-2,8E-04	1,0E-03
Photochemical ozone formation (POCP)	PET/PE	*1,2*	1,5E-03	-4,8E-04	1,0E-03	1,8E-03	-5,7E-04	1,2E-03
Acidification (AP)	PET/PE	*1,3*	2,8E-03	-7,2E-04	2,1E-03	3,6E-03	-9,4E-04	2,7E-03
Global warming (GWP)	PET/PE	*1,3*	9,6E-03	-3,3E-03	6,3E-03	1,2E-02	-4,3E-03	8,2E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	2,2E-02	-8,7E-03	1,4E-02	2,5E-02	-9,5E-03	1,5E-02
Hazardous waste	PET/PE	*1,1*	6,2E-02	-5,6E-03	5,6E-02	6,8E-02	-6,2E-03	6,2E-02
Slag and ashes	PET/PE	*1,1*	2,5E-03	9,6E-05	2,6E-03	2,8E-03	1,1E-04	2,9E-03
Nuclear waste	PET/PE	*1,1*	1,3E-02	1,8E-03	1,4E-02	1,4E-02	2,0E-03	1,6E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	8,3E-03	-2,4E-03	5,9E-03	1,9E-04	-5,5E-05	1,4E-04
Coal	l/year	*0,0058*	3,9E-02	-3,5E-03	3,6E-02	2,3E-04	-2,1E-05	2,1E-04
Brown coal	l/year	*0,0026*	1,4E-03	-2,0E-04	1,2E-03	3,8E-06	-5,1E-07	3,2E-06
Natural gas	l/year	*0,016*	1,0E-02	-1,0E-03	9,0E-03	1,6E-04	-1,6E-05	1,4E-04
Aluminium (Al)	l/year	*0,0051*	3,8E-01	-6,6E-02	3,1E-01	1,9E-03	-3,4E-04	1,6E-03
Iron (Fe)	l/year	*0,0085*	1,0E-01	-9,3E-02	6,6E-03	8,5E-04	-7,9E-04	5,6E-05
Manganese (Mn)	l/year	*0,012*	1,5E-07	-1,3E-08	1,3E-07	1,7E-09	-1,6E-10	1,6E-09
Tin (Sn)	l/year	*0,037*	6,0E-01	0,0E+00	6,0E-01	2,2E-02	0,0E+00	2,2E-02

Normalisation: 33cl steel can (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	**Normalisation reference**		**Characterisation results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	2,5E-01	-5,3E-02	1,9E-01	8,3E-04	-1,8E-04	6,5E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	2,3E-02	-7,3E-03	1,6E-02	1,2E-03	-3,7E-04	7,9E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	2,7E-01	-6,9E-02	2,0E-01	2,2E-03	-5,5E-04	1,6E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	6,4E+01	-2,2E+01	4,2E+01	7,4E-03	-2,5E-03	4,9E-03

Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	2,3E+04	-9,0E+03	1,4E+04	1,7E-02	-6,6E-03	1,0E-02
Hazardous waste	g/pers/year	*20700*	9,9E+02	-8,9E+01	9,0E+02	4,8E-02	-4,3E-03	4,3E-02
Slag and ashes	g/pers/year	*3,20E+05*	6,8E+02	2,6E+01	7,1E+02	1,9E-03	7,3E-05	2,0E-03
Nuclear waste	g/pers/year	*159*	1,5E+00	2,2E-01	1,8E+00	9,6E-03	1,4E-03	1,1E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	3,8E+03	-1,1E+03	2,7E+03	6,4E-03	-1,8E-03	4,5E-03
Coal	g/pers/year	*9,31E+05*	2,8E+04	-2,5E+03	2,6E+04	3,0E-02	-2,7E-03	2,7E-02
Brown coal	g/pers/year	*2,50E+05*	2,8E+02	-3,8E+01	2,4E+02	1,1E-03	-1,5E-04	9,6E-04
Natural gas	g/pers/year	*3,10E+05*	2,4E+03	-2,4E+02	2,1E+03	7,7E-03	-7,8E-04	6,9E-03
Aluminium (Al)	g/pers/year	*3100*	9,9E+02	-1,7E+02	8,2E+02	2,9E-01	-5,1E-02	2,4E-01
Iron (Fe)	g/pers/year	*1,00E+05*	7,7E+03	-7,2E+03	5,0E+02	7,7E-02	-7,2E-02	5,0E-03
Manganese (Mn)	g/pers/year	*1800*	2,0E-04	-1,8E-05	1,8E-04	1,1E-07	-1,0E-08	1,0E-07
Tin (Sn)	g/pers/year	*40*	1,9E+01	0,0E+00	1,9E+01	4,6E-01	0,0E+00	4,6E-01

Weighting: 33cl steel can (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	8,3E-04	-1,8E-04	6,5E-04	9,9E-04	-2,1E-04	7,8E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	1,2E-03	-3,7E-04	7,9E-04	1,4E-03	-4,4E-04	9,5E-04
Acidification (AP)	PET/PE	*1,3*	2,2E-03	-5,5E-04	1,6E-03	2,8E-03	-7,2E-04	2,1E-03
Global warming (GWP)	PET/PE	*1,3*	7,4E-03	-2,5E-03	4,9E-03	9,6E-03	-3,3E-03	6,3E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	1,7E-02	-6,6E-03	1,0E-02	1,9E-02	-7,3E-03	1,2E-02
Hazardous waste	PET/PE	*1,1*	4,8E-02	-4,3E-03	4,3E-02	5,2E-02	-4,7E-03	4,8E-02
Slag and ashes	PET/PE	*1,1*	1,9E-03	7,3E-05	2,0E-03	2,1E-03	8,1E-05	2,2E-03
Nuclear waste	PET/PE	*1,1*	9,6E-03	1,4E-03	1,1E-02	1,1E-02	1,5E-03	1,2E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	1/year	*0,023*	6,4E-03	-1,8E-03	4,5E-03	1,5E-04	-4,2E-05	1,0E-04
Coal	1/year	*0,0058*	3,0E-02	-2,7E-03	2,7E-02	1,8E-04	-1,6E-05	1,6E-04
Brown coal	1/year	*0,0026*	1,1E-03	-1,5E-04	9,6E-04	2,9E-06	-3,9E-07	2,5E-06
Natural gas	1/year	*0,016*	7,7E-03	-7,8E-04	6,9E-03	1,2E-04	-1,2E-05	1,1E-04
Aluminium (Al)	1/year	*0,0051*	2,9E-01	-5,1E-02	2,4E-01	1,5E-03	-2,6E-04	1,2E-03
Iron (Fe)	1/year	*0,0085*	7,7E-02	-7,2E-02	5,0E-03	6,5E-04	-6,1E-04	4,3E-05
Manganese (Mn)	1/year	*0,012*	1,1E-07	-1,0E-08	1,0E-07	1,3E-09	-1,2E-10	1,2E-09
Tin (Sn)	1/year	*0,037*	4,6E-01	0,0E+00	4,6E-01	1,7E-02	0,0E+00	1,7E-02

Normalisation: 50cl steel can (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	**Normalisation reference**		**Characterisation results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	2,6E-01	-5,5E-02	2,0E-01	8,7E-04	-1,9E-04	6,9E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	2,6E-02	-7,9E-03	1,8E-02	1,3E-03	-4,0E-04	8,9E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	2,7E-01	-7,1E-02	2,0E-01	2,2E-03	-5,7E-04	1,6E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	6,7E+01	-2,3E+01	4,4E+01	7,7E-03	-2,7E-03	5,1E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	2,5E+04	-9,9E+03	1,5E+04	1,9E-02	-7,4E-03	1,1E-02
Hazardous waste	g/pers/year	*20700*	1,1E+03	-7,0E+01	1,0E+03	5,2E-02	-3,4E-03	4,9E-02
Slag and ashes	g/pers/year	*3,20E+05*	7,4E+02	-2,3E+00	7,4E+02	2,1E-03	-6,7E-06	2,1E-03
Nuclear waste	g/pers/year	*159*	1,8E+00	1,6E-01	2,0E+00	1,1E-02	9,9E-04	1,2E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	4,0E+03	-1,1E+03	2,9E+03	6,8E-03	-1,9E-03	4,9E-03
Coal	g/pers/year	*9,31E+05*	2,9E+04	-2,0E+03	2,7E+04	3,1E-02	-2,1E-03	2,9E-02
Brown coal	g/pers/year	*2,50E+05*	2,9E+02	-3,4E+01	2,6E+02	1,2E-03	-1,4E-04	1,0E-03
Natural gas	g/pers/year	*3,10E+05*	2,7E+03	-2,0E+02	2,5E+03	8,6E-03	-6,5E-04	7,9E-03
Aluminium (Al)	g/pers/year	*3100*	8,5E+02	-1,5E+02	7,0E+02	2,5E-01	-4,4E-02	2,1E-01
Iron (Fe)	g/pers/year	*1,00E+05*	9,0E+03	-8,3E+03	6,4E+02	9,0E-02	-8,3E-02	6,4E-03
Manganese (Mn)	g/pers/year	*1800*	2,1E-04	-1,4E-05	1,9E-04	1,2E-07	-7,8E-09	1,1E-07
Tin (Sn)	g/pers/year	*40*	2,2E+01	0,0E+00	2,2E+01	5,5E-01	0,0E+00	5,5E-01

Weighting: 50cl steel can (base case)

Functional unit: 120.9 litres of beer (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	8,7E-04	-1,9E-04	6,9E-04	1,0E-03	-2,2E-04	8,2E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	1,3E-03	-4,0E-04	8,9E-04	1,5E-03	-4,7E-04	1,1E-03
Acidification (AP)	PET/PE	*1,3*	2,2E-03	-5,7E-04	1,6E-03	2,9E-03	-7,4E-04	2,1E-03
Global warming (GWP)	PET/PE	*1,3*	7,7E-03	-2,7E-03	5,1E-03	1,0E-02	-3,5E-03	6,6E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	1,9E-02	-7,4E-03	1,1E-02	2,1E-02	-8,1E-03	1,3E-02
Hazardous waste	PET/PE	*1,1*	5,2E-02	-3,4E-03	4,9E-02	5,7E-02	-3,7E-03	5,4E-02
Slag and ashes	PET/PE	*1,1*	2,1E-03	-6,7E-06	2,1E-03	2,3E-03	-7,4E-06	2,3E-03
Nuclear waste	PET/PE	*1,1*	1,1E-02	9,9E-04	1,2E-02	1,3E-02	1,1E-03	1,4E-02
Resource consumption (RR 90)								
Non-renewable								
Oil	1/year	*0,023*	6,8E-03	-1,9E-03	4,9E-03	1,6E-04	-4,3E-05	1,1E-04
Coal	1/year	*0,0058*	3,1E-02	-2,1E-03	2,9E-02	1,8E-04	-1,2E-05	1,7E-04
Brown coal	1/year	*0,0026*	1,2E-03	-1,4E-04	1,0E-03	3,1E-06	-3,6E-07	2,7E-06
Natural gas	1/year	*0,016*	8,6E-03	-6,5E-04	7,9E-03	1,4E-04	-1,0E-05	1,3E-04
Aluminium (Al)	1/year	*0,0051*	2,5E-01	-4,4E-02	2,1E-01	1,3E-03	-2,2E-04	1,1E-03
Iron (Fe)	1/year	*0,0085*	9,0E-02	-8,3E-02	6,4E-03	7,6E-04	-7,1E-04	5,4E-05
Manganese (Mn)	1/year	*0,012*	1,2E-07	-7,8E-09	1,1E-07	1,4E-09	-9,4E-11	1,3E-09
Tin (Sn)	1/year	*0,037*	5,5E-01	0,0E+00	5,5E-01	2,0E-02	0,0E+00	2,0E-02

Normalisation: 50cl steel can (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	2,0E-01	-4,2E-02	1,6E-01	6,7E-04	-1,4E-04	5,3E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	2,0E-02	-6,1E-03	1,4E-02	9,8E-04	-3,0E-04	6,8E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	2,1E-01	-5,5E-02	1,6E-01	1,7E-03	-4,4E-04	1,3E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	5,2E+01	-1,8E+01	3,4E+01	5,9E-03	-2,0E-03	3,9E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	g/pers/year	*1,35E+06*	1,9E+04	-7,6E+03	1,2E+04	1,4E-02	-5,6E-03	8,7E-03
Hazardous waste	g/pers/year	*20700*	8,3E+02	-5,4E+01	7,8E+02	4,0E-02	-2,6E-03	3,7E-02
Slag and ashes	g/pers/year	*3,20E+05*	5,7E+02	-1,8E+00	5,7E+02	1,6E-03	-5,2E-06	1,6E-03
Nuclear waste	g/pers/year	*159*	1,4E+00	1,2E-01	1,5E+00	8,7E-03	7,6E-04	9,5E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	3,1E+03	-8,4E+02	2,2E+03	5,2E-03	-1,4E-03	3,8E-03
Coal	g/pers/year	*9,31E+05*	2,2E+04	-1,5E+03	2,1E+04	2,4E-02	-1,6E-03	2,2E-02
Brown coal	g/pers/year	*2,50E+05*	2,3E+02	-2,6E+01	2,0E+02	9,0E-04	-1,1E-04	8,0E-04
Natural gas	g/pers/year	*3,10E+05*	2,0E+03	-1,5E+02	1,9E+03	6,6E-03	-5,0E-04	6,1E-03
Aluminium (Al)	g/pers/year	*3100*	6,6E+02	-1,1E+02	5,4E+02	1,9E-01	-3,4E-02	1,6E-01
Iron (Fe)	g/pers/year	*1,00E+05*	6,9E+03	-6,4E+03	4,9E+02	6,9E-02	-6,4E-02	4,9E-03
Manganese (Mn)	g/pers/year	*1800*	1,6E-04	-1,1E-05	1,5E-04	8,9E-08	-6,0E-09	8,3E-08
Tin (Sn)	g/pers/year	*40*	1,7E+01	0,0E+00	1,7E+01	4,2E-01	0,0E+00	4,2E-01

Weighting: 50cl steel can (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	6,7E-04	-1,4E-04	5,3E-04	8,0E-04	-1,7E-04	6,3E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	9,8E-04	-3,0E-04	6,8E-04	1,2E-03	-3,6E-04	8,2E-04
Acidification (AP)	PET/PE	*1,3*	1,7E-03	-4,4E-04	1,3E-03	2,2E-03	-5,7E-04	1,6E-03
Global warming (GWP)	PET/PE	*1,3*	5,9E-03	-2,0E-03	3,9E-03	7,7E-03	-2,7E-03	5,1E-03
Human toxicity: via air (HTA)	PET/PE	*2,8*	1,2E-03	-4,9E-04	7,0E-04	3,3E-03	-1,4E-03	2,0E-03

Waste	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	1,4E-02	-5,6E-03	8,7E-03	1,6E-02	-6,2E-03	9,6E-03
Hazardous waste	PET/PE	*1,1*	4,0E-02	-2,6E-03	3,7E-02	4,4E-02	-2,9E-03	4,1E-02
Slag and ashes	PET/PE	*1,1*	1,6E-03	-5,2E-06	1,6E-03	1,8E-03	-5,7E-06	1,8E-03
Nuclear waste	PET/PE	*1,1*	8,7E-03	7,6E-04	9,5E-03	9,6E-03	8,4E-04	1,0E-02

Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	5,2E-03	-1,4E-03	3,8E-03	1,2E-04	-3,3E-05	8,7E-05
Coal	l/year	*0,0058*	2,4E-02	-1,6E-03	2,2E-02	1,4E-04	-9,5E-06	1,3E-04
Brown coal	l/year	*0,0026*	9,0E-04	-1,1E-04	8,0E-04	2,3E-06	-2,7E-07	2,1E-06
Natural gas	l/year	*0,016*	6,6E-03	-5,0E-04	6,1E-03	1,1E-04	-8,0E-06	9,7E-05
Aluminium (Al)	l/year	*0,0051*	1,9E-01	-3,4E-02	1,6E-01	9,8E-04	-1,7E-04	8,1E-04
Iron (Fe)	l/year	*0,0085*	6,9E-02	-6,4E-02	4,9E-03	5,8E-04	-5,4E-04	4,2E-05
Manganese (Mn)	l/year	*0,012*	8,9E-08	-6,0E-09	8,3E-08	1,1E-09	-7,2E-11	9,9E-10
Tin (Sn)	l/year	*0,037*	4,2E-01	0,0E+00	4,2E-01	1,5E-02	0,0E+00	1,5E-02

Normalisation: 50 cl refillable PET bottles (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	6,4E-02	-8,1E-03	5,6E-02	2,1E-04	-2,7E-05	1,9E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	2,1E-02	-6,1E-03	1,4E-02	1,0E-03	-3,0E-04	7,2E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	6,9E-02	-1,2E-02	5,7E-02	5,6E-04	-1,0E-04	4,6E-04
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	8,6E+00	-8,0E-01	7,8E+00	9,9E-04	-9,2E-05	9,0E-04
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	1,4E+03	5,7E+01	1,5E+03	1,1E-03	4,2E-05	1,1E-03
Hazardous waste	g/pers/year	*20700*	9,7E+01	-3,5E+01	6,2E+01	4,7E-03	-1,7E-03	3,0E-03
Slag and ashes	g/pers/year	*3,20E+05*	4,7E+01	2,3E+00	5,0E+01	1,4E-04	6,6E-06	1,4E-04
Nuclear waste	g/pers/year	*159*	8,1E-01	6,9E-03	8,1E-01	5,1E-03	4,3E-05	5,1E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	1,8E+03	-6,1E+02	1,2E+03	3,1E-03	-1,0E-03	2,0E-03
Coal	g/pers/year	*9,31E+05*	2,0E+03	-4,1E+01	2,0E+03	2,2E-03	-4,4E-05	2,1E-03
Brown coal	g/pers/year	*2,50E+05*	2,7E+01	-3,0E+00	2,4E+01	1,1E-04	-1,2E-05	9,5E-05
Natural gas	g/pers/year	*3,10E+05*	7,1E+02	-2,7E+02	4,4E+02	2,3E-03	-8,6E-04	1,4E-03
Aluminium (Al)	g/pers/year	*3100*	9,0E-02	-3,4E-02	5,6E-02	2,7E-05	-9,9E-06	1,7E-05
Iron (Fe)	g/pers/year	*1,00E+05*	1,4E-02	-4,4E-03	9,8E-03	1,4E-07	-4,4E-08	9,8E-08
Manganese (Mn)	g/pers/year	*1800*	2,4E-02	-8,6E-03	1,6E-02	1,4E-05	-4,8E-06	8,7E-06

Weighting: 50 cl refillable PET bottles (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	2,1E-04	-2,7E-05	1,9E-04	2,6E-04	-3,3E-05	2,2E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	1,0E-03	-3,0E-04	7,2E-04	1,2E-03	-3,6E-04	8,7E-04
Acidification (AP)	PET/PE	*1,3*	5,6E-04	-1,0E-04	4,6E-04	7,3E-04	-1,3E-04	6,0E-04
Global warming (GWP)	PET/PE	*1,3*	9,9E-04	-9,2E-05	9,0E-04	1,3E-03	-1,2E-04	1,2E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	1,1E-03	4,2E-05	1,1E-03	1,2E-03	4,6E-05	1,2E-03
Hazardous waste	PET/PE	*1,1*	4,7E-03	-1,7E-03	3,0E-03	5,2E-03	-1,9E-03	3,3E-03
Slag and ashes	PET/PE	*1,1*	1,4E-04	6,6E-06	1,4E-04	1,5E-04	7,2E-06	1,6E-04
Nuclear waste	PET/PE	*1,1*	5,1E-03	4,3E-05	5,1E-03	5,6E-03	4,8E-05	5,6E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	1/year	*0,023*	3,1E-03	-1,0E-03	2,0E-03	7,0E-05	-2,4E-05	4,7E-05
Coal	1/year	*0,0058*	2,2E-03	-4,4E-05	2,1E-03	1,3E-05	-2,5E-07	1,2E-05
Brown coal	1/year	*0,0026*	1,1E-04	-1,2E-05	9,5E-05	2,8E-07	-3,1E-08	2,5E-07
Natural gas	1/year	*0,016*	2,3E-03	-8,6E-04	1,4E-03	3,7E-05	-1,4E-05	2,3E-05
Aluminium (Al)	1/year	*0,0051*	2,7E-05	-9,9E-06	1,7E-05	1,4E-07	-5,1E-08	8,4E-08
Iron (Fe)	1/year	*0,0085*	1,4E-07	-4,4E-08	9,8E-08	1,2E-09	-3,7E-10	8,3E-10
Manganese (Mn)	1/year	*0,012*	1,4E-05	-4,8E-06	8,7E-06	1,6E-07	-5,7E-08	1,0E-07

Normalisation: 150 cl refillable PET bottles (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	5,2E-02	-4,9E-03	4,7E-02	1,7E-04	-1,6E-05	1,6E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,4E-02	-3,7E-03	1,0E-02	7,0E-04	-1,8E-04	5,1E-04
Acidification (AP)	kg SO2-eq/pers/year	*124*	5,1E-02	-7,4E-03	4,4E-02	4,1E-04	-5,9E-05	3,5E-04
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	7,2E+00	-7,1E-01	6,5E+00	8,3E-04	-8,1E-05	7,5E-04
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	g/pers/year	*1,35E+06*	1,2E+03	-6,0E+01	1,2E+03	9,1E-04	-4,4E-05	8,6E-04
Hazardous waste	g/pers/year	*20700*	8,6E+01	-2,8E+01	5,8E+01	4,1E-03	-1,3E-03	2,8E-03
Slag and ashes	g/pers/year	*3,20E+05*	4,0E+01	1,3E+00	4,1E+01	1,1E-04	3,6E-06	1,2E-04
Nuclear waste	g/pers/year	*159*	7,6E-01	5,7E-03	7,7E-01	4,8E-03	3,6E-05	4,8E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	1,2E+03	-3,5E+02	8,9E+02	2,1E-03	-5,9E-04	1,5E-03
Coal	g/pers/year	*9,31E+05*	1,9E+03	-5,5E+01	1,8E+03	2,0E-03	-5,9E-05	1,9E-03
Brown coal	g/pers/year	*2,50E+05*	2,5E+01	-2,6E+00	2,2E+01	1,0E-04	-1,0E-05	9,0E-05
Natural gas	g/pers/year	*3,10E+05*	4,7E+02	-1,7E+02	3,0E+02	1,5E-03	-5,4E-04	9,7E-04
Aluminium (Al)	g/pers/year	*3100*	4,6E-02	-1,6E-02	3,0E-02	1,4E-05	-4,7E-06	8,9E-06
Iron (Fe)	g/pers/year	*1,00E+05*	8,9E-03	-2,4E-03	6,5E-03	8,9E-08	-2,4E-08	6,5E-08
Manganese (Mn)	g/pers/year	*1800*	1,6E-02	-5,7E-03	1,0E-02	9,0E-06	-3,2E-06	5,8E-06

Weighting: 150 cl refillable PET bottles (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	1,7E-04	-1,6E-05	1,6E-04	2,1E-04	-2,0E-05	1,9E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	7,0E-04	-1,8E-04	5,1E-04	8,4E-04	-2,2E-04	6,2E-04
Acidification (AP)	PET/PE	*1,3*	4,1E-04	-5,9E-05	3,5E-04	5,4E-04	-7,7E-05	4,6E-04
Global warming (GWP)	PET/PE	*1,3*	8,3E-04	-8,1E-05	7,5E-04	1,1E-03	-1,1E-04	9,7E-04
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	PET/PE	*1,1*	9,1E-04	-4,4E-05	8,6E-04	1,0E-03	-4,9E-05	9,5E-04
Hazardous waste	PET/PE	*1,1*	4,1E-03	-1,3E-03	2,8E-03	4,5E-03	-1,5E-03	3,1E-03
Slag and ashes	PET/PE	*1,1*	1,1E-04	3,6E-06	1,2E-04	1,2E-04	4,0E-06	1,3E-04
Nuclear waste	PET/PE	*1,1*	4,8E-03	3,6E-05	4,8E-03	5,3E-03	3,9E-05	5,3E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	2,1E-03	-5,9E-04	1,5E-03	4,8E-05	-1,4E-05	3,5E-05
Coal	l/year	*0,0058*	2,0E-03	-5,9E-05	1,9E-03	1,2E-05	-3,4E-07	1,1E-05
Brown coal	l/year	*0,0026*	1,0E-04	-1,0E-05	9,0E-05	2,6E-07	-2,7E-08	2,3E-07
Natural gas	l/year	*0,016*	1,5E-03	-5,4E-04	9,7E-04	2,4E-05	-8,6E-06	1,6E-05
Aluminium (Al)	l/year	*0,0051*	1,4E-05	-4,7E-06	8,9E-06	6,9E-08	-2,4E-08	4,5E-08
Iron (Fe)	l/year	*0,0085*	8,9E-08	-2,4E-08	6,5E-08	7,6E-10	-2,1E-10	5,5E-10
Manganese (Mn)	l/year	*0,012*	9,0E-06	-3,2E-06	5,8E-06	1,1E-07	-3,8E-08	7,0E-08

Normalisation: 50 cl disposable PET bottles (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Normalisation reference		Characterisation results			Normalisation results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	2,5E-01	-6,5E-02	1,8E-01	8,2E-04	-2,2E-04	6,1E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	1,4E-01	-6,0E-02	8,2E-02	7,1E-03	-3,0E-03	4,1E-03
Acidification (AP)	kg SO2-eq/pers/year	*124*	4,0E-01	-1,1E-01	2,9E-01	3,2E-03	-8,8E-04	2,3E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	3,4E+01	-7,8E+00	2,6E+01	3,9E-03	-9,0E-04	3,0E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	g/pers/year	*1,35E+06*	2,9E+03	1,5E+03	4,4E+03	2,2E-03	1,1E-03	3,3E-03
Hazardous waste	g/pers/year	*20700*	1,4E+02	-7,7E+01	6,3E+01	6,8E-03	-3,7E-03	3,1E-03
Slag and ashes	g/pers/year	*3,20E+05*	2,8E+02	-1,7E+01	2,6E+02	7,9E-04	-4,8E-05	7,4E-04
Nuclear waste	g/pers/year	*159*	1,1E+00	1,7E-01	1,3E+00	7,0E-03	1,1E-03	8,0E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	7,4E+03	-3,4E+03	4,1E+03	1,3E-02	-5,7E-03	6,9E-03
Coal	g/pers/year	*9,31E+05*	4,8E+03	-1,5E+02	4,6E+03	5,1E-03	-1,6E-04	5,0E-03
Brown coal	g/pers/year	*2,50E+05*	4,6E+01	-5,4E+00	4,1E+01	1,9E-04	-2,1E-05	1,6E-04
Natural gas	g/pers/year	*3,10E+05*	3,4E+03	-1,7E+03	1,7E+03	1,1E-02	-5,4E-03	5,5E-03
Aluminium (Al)	g/pers/year	*3100*	5,0E-01	-2,2E-01	2,8E-01	1,5E-04	-6,5E-05	8,2E-05
Iron (Fe)	g/pers/year	*1,00E+05*	5,9E-02	-2,4E-02	3,5E-02	5,9E-07	-2,4E-07	3,5E-07
Manganese (Mn)	g/pers/year	*1800*	2,6E-01	-1,2E-01	1,4E-01	1,4E-04	-6,5E-05	7,9E-05

Weighting: 50 cl disposable PET bottles (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	8,2E-04	-2,2E-04	6,1E-04	9,9E-04	-2,6E-04	7,3E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	7,1E-03	-3,0E-03	4,1E-03	8,5E-03	-3,6E-03	4,9E-03
Acidification (AP)	PET/PE	*1,3*	3,2E-03	-8,8E-04	2,3E-03	4,2E-03	-1,1E-03	3,0E-03
Global warming (GWP)	PET/PE	*1,3*	3,9E-03	-9,0E-04	3,0E-03	5,1E-03	-1,2E-03	3,9E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	2,2E-03	1,1E-03	3,3E-03	2,4E-03	1,2E-03	3,6E-03
Hazardous waste	PET/PE	*1,1*	6,8E-03	-3,7E-03	3,1E-03	7,5E-03	-4,1E-03	3,4E-03
Slag and ashes	PET/PE	*1,1*	7,9E-04	-4,8E-05	7,4E-04	8,7E-04	-5,3E-05	8,2E-04
Nuclear waste	PET/PE	*1,1*	7,0E-03	1,1E-03	8,0E-03	7,7E-03	1,2E-03	8,8E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	1,3E-02	-5,7E-03	6,9E-03	2,9E-04	-1,3E-04	1,6E-04
Coal	l/year	*0,0058*	5,1E-03	-1,6E-04	5,0E-03	3,0E-05	-9,4E-07	2,9E-05
Brown coal	l/year	*0,0026*	1,9E-04	-2,1E-05	1,6E-04	4,8E-07	-5,6E-08	4,3E-07
Natural gas	l/year	*0,016*	1,1E-02	-5,4E-03	5,5E-03	1,7E-04	-8,6E-05	8,8E-05
Aluminium (Al)	l/year	*0,0051*	1,5E-04	-6,5E-05	8,2E-05	7,5E-07	-3,3E-07	4,2E-07
Iron (Fe)	l/year	*0,0085*	5,9E-07	-2,4E-07	3,5E-07	5,0E-09	-2,0E-09	3,0E-09
Manganese (Mn)	l/year	*0,012*	1,4E-04	-6,5E-05	7,9E-05	1,7E-06	-7,8E-07	9,5E-07

Normalisation: 150 cl disposable PET bottles (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	**Normalisation reference**		**Characterisation results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Nutrient enrichment (NP)	kg NO3- -eq/pers/year	*298*	1,4E-01	-2,9E-02	1,1E-01	4,7E-04	-9,8E-05	3,7E-04
Photochemical ozone formation (POCP)	kg C2H4-eq/pers/year	*20*	7,3E-02	-2,7E-02	4,6E-02	3,7E-03	-1,4E-03	2,3E-03
Acidification (AP)	kg SO2-eq/pers/year	*124*	2,1E-01	-4,9E-02	1,6E-01	1,7E-03	-4,0E-04	1,3E-03
Global warming (GWP)	kg CO2-eq/pers/year	*8700*	1,9E+01	-4,2E+00	1,5E+01	2,2E-03	-4,8E-04	1,7E-03
Waste	**Normalisation reference**		**Inventory results**			**Normalisation results**		
	Unit	**Value**	**Packaging system**	**Effects on other life cycles**	**Total**	**Packaging system**	**Effects on other life cycles**	**Total**
Bulk waste	g/pers/year	*1,35E+06*	1,8E+03	4,1E+02	2,3E+03	1,4E-03	3,0E-04	1,7E-03
Hazardous waste	g/pers/year	*20700*	1,0E+02	-6,5E+01	3,5E+01	4,8E-03	-3,1E-03	1,7E-03
Slag and ashes	g/pers/year	*3,20E+05*	1,5E+02	-7,3E+00	1,5E+02	4,4E-04	-2,1E-05	4,2E-04
Nuclear waste	g/pers/year	*159*	8,9E-01	8,9E-02	9,8E-01	5,6E-03	5,6E-04	6,1E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	g/pers/year	*5,90E+05*	4,0E+03	-1,6E+03	2,4E+03	6,8E-03	-2,7E-03	4,1E-03
Coal	g/pers/year	*9,31E+05*	3,0E+03	-9,8E+01	2,9E+03	3,2E-03	-1,0E-04	3,1E-03
Brown coal	g/pers/year	*2,50E+05*	3,3E+01	-4,4E+00	2,8E+01	1,3E-04	-1,8E-05	1,1E-04
Natural gas	g/pers/year	*3,10E+05*	1,8E+03	-8,3E+02	9,6E+02	5,8E-03	-2,7E-03	3,1E-03
Aluminium (Al)	g/pers/year	*3100*	2,5E-01	-9,6E-02	1,5E-01	7,3E-05	-2,8E-05	4,5E-05
Iron (Fe)	g/pers/year	*1,00E+05*	4,8E-02	-1,8E-02	3,0E-02	4,8E-07	-1,8E-07	3,0E-07
Manganese (Mn)	g/pers/year	*1800*	1,3E-01	-5,3E-02	7,7E-02	7,2E-05	-2,9E-05	4,3E-05

Weighting: 150 cl disposable PET bottles (base case)

Functional unit: 92.8 litres of softdrinks (annual-96 in Denmark)

Impact category	Weighting factor		Normalisation results			Weighting results		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Nutrient enrichment (NP)	PET/PE	*1,2*	4,7E-04	-9,8E-05	3,7E-04	5,6E-04	-1,2E-04	4,4E-04
Photochemical ozone formation (POCP)	PET/PE	*1,2*	3,7E-03	-1,4E-03	2,3E-03	4,4E-03	-1,6E-03	2,8E-03
Acidification (AP)	PET/PE	*1,3*	1,7E-03	-4,0E-04	1,3E-03	2,2E-03	-5,1E-04	1,7E-03
Global warming (GWP)	PET/PE	*1,3*	2,2E-03	-4,8E-04	1,7E-03	2,9E-03	-6,3E-04	2,2E-03
Waste	**Weighting factor**		**Normalisation results**			**Weighting results**		
	Unit	Value	Packaging system	Effects on other life cycles	Total	Packaging system	Effects on other life cycles	Total
Bulk waste	PET/PE	*1,1*	1,4E-03	3,0E-04	1,7E-03	1,5E-03	3,3E-04	1,8E-03
Hazardous waste	PET/PE	*1,1*	4,8E-03	-3,1E-03	1,7E-03	5,3E-03	-3,4E-03	1,9E-03
Slag and ashes	PET/PE	*1,1*	4,4E-04	-2,1E-05	4,2E-04	4,8E-04	-2,3E-05	4,6E-04
Nuclear waste	PET/PE	*1,1*	5,6E-03	5,6E-04	6,1E-03	6,1E-03	6,2E-04	6,7E-03
Resource consumption (RR 90)								
Non-renewable								
Oil	l/year	*0,023*	6,8E-03	-2,7E-03	4,1E-03	1,6E-04	-6,2E-05	9,4E-05
Coal	l/year	*0,0058*	3,2E-03	-1,0E-04	3,1E-03	1,9E-05	-6,1E-07	1,8E-05
Brown coal	l/year	*0,0026*	1,3E-04	-1,8E-05	1,1E-04	3,4E-07	-4,6E-08	2,9E-07
Natural gas	l/year	*0,016*	5,8E-03	-2,7E-03	3,1E-03	9,2E-05	-4,3E-05	4,9E-05
Aluminium (Al)	l/year	*0,0051*	7,3E-05	-2,8E-05	4,5E-05	3,7E-07	-1,4E-07	2,3E-07
Iron (Fe)	l/year	*0,0085*	4,8E-07	-1,8E-07	3,0E-07	4,1E-09	-1,5E-09	2,6E-09
Manganese (Mn)	l/year	*0,012*	7,2E-05	-2,9E-05	4,3E-05	8,7E-07	-3,5E-07	5,1E-07

Annex C:

International panel on technology level in LCA

C.1 Introduction

This annex presents the work and conclusions from the international panel of LCA experts, which was convened for the specific purpose of advising on the choice of technological level for the study, with special emphasis on the energy scenarios.

Panel members

The panel members were:

- Gjalt Huppes, CML, Leiden, The Netherlands
- Tomas Ekvall and Tomas Rydberg, Chalmers Industriteknik, Gothenburg, Sweden
- Rolf Frischknecht, ETH Zürich, Switzerland
- Wulf-Peter Schmidt, Tech. Univ. Berlin, Germany, and
- Henrik Wenzel and Bo Weidema (co-ordinator), IPU, Denmark.

Procedure

The panel was given the following initial input from the co-ordinator (see section C.2):

- an early version of the goal definition for the study,
- 3 arguments/assumptions to be commented by the panel (on when to use site specific, modern or marginal data for the study), and
- 3 example cases to illustrate the problem (electricity for production, artificial fertiliser and animal manure for agricultural production and three alternative Swedish municipal waste water treatment systems).

The panel communicated by e-mail to reach a general agreement. In the course of the discussion, the co-ordinator introduced two further questions:

- on how to determine the marginal, and
- on how to deal with in-house production of electricity and heat.

Objective

The objective of the panel discussion was to determine, as far as possible, the general theoretical basis for choice of technology (especially for the energy scenarios) in a specific life cycle assessment. The conclusions are presented in section C.3.

C.2 Initial input

Presentation of the specific case
The following is the tentative goal definition for the specific case for which we should attempt to agree on the choice of technological level (at least for the energy scenario):

"The study is a life cycle assessment comparing the potential environmental impacts associated with different packaging systems for beer and softdrinks in Denmark under the expected operating conditions in the coming years, more specifically determined as the years 1998-2000.

Especially, it is assumed that all the analysed systems will operate under a return scheme in which a deposit is paid by the consumer along with the beverage and paid back when returning the package to the retailer.

The study shall provide background information for the administration of the Danish national standards for packaging which may be placed on the market, referring to the EU directive 94/62/EC on packaging and packaging waste.

At present, the Danish standards allow only refillable packagings to be used for beer and soft drink. Thus, the question to be investigated is whether a continuation of the present refillable packaging systems will have a lower potential impact on the environment than if other packaging systems are introduced alongside or as an alternative to the present systems.

The study is an update of a previous study performed in the period 1992 to 1996. The updating relates to:

- improvements and updating of data,
- changed conditions since the previous study, and
- application of the most recent standards (ISO DIS 14040 and 14041) and methodology (Wenzel et al. 1997).

The study in financed by the Danish Environmental Agency and is intended for publication."

From this goal definition it follows that the data which are to be collected should represent as well as possible the technologies which are likely to be involved during the years 1998-2000 assuming different combinations of packaging systems to be in operation in Denmark.

Also it follows from the goal definition that we are comparing alternative systems.

General arguments/assumptions on technological level, which I should like you to comment

The following text relates only to comperative life cycle assessments relating to the immediate future.

If the actual conditions under which a specific unit process will operate in the immediate future can be determined, then this actual site specific data shall be used.

When this is not the case, and with the exception stated below, data for the modern technology (defined as the technology typically installed at present when installing new machinery) shall be used, as this gives a reasonable approximation of the average technology which is likely to be applied in the period of 1 to 3 years from the present.

When general constraints apply to the modern technology, i.e. if in practice the modern (preferred) technology cannot be installed to the extent desired as reflected by the general market demand, the modern technology will anyway be used up to its maximum capacity, and the additional demand caused by the product system under study will not affect this. Under normal market conditions, this means that the additional demand will be covered by the most competitive technology, which is not subject to general constraints. This is called the marginal technology, since this is the technology which will be taken into use or out of use as a result of marginal changes in the demand. Thus, to reflect the actual technology involved, data for the marginal technology should be used, when the modern technology is subject to general capacity constraints.

Illustrative examples that may be useful for the discussion

Example 1. Norwegian electricity use. This example is an extreme version, which may clarify some of the more subtle discussions:

When analysing two alternative products, one produced in Denmark (electricity mainly modern coal-fired) and one in Norway (electricity mainly water based), the actual technology which will be used to produce the additional electricity for the analysed product is the same, namely Danish (coal-based, since this is the most competitive, unconstrained technology). This is due to the fact that the Norwegian hydro-power (which is the ultimately cheapest and therefore the most competitive) in practice is limited to the present capacity. Therefore, the Norwegian factory which increases its production as a result of the life cycle assessment, will cause an increase in the demand for electricity which cannot be covered by the hydro-power (since it is already used completely). The increase in demand therefore in practice causes an increase in the Norwegian import from Denmark or alternatively, the Norwegians may decide to build a non-hydro power station to make up for the increase. The technology will be the same (modern, unconstrained) but the geographical position of the marginal power plant may be determined by other factors.

The logic is equivalent if you move from a high electricity demand to a lower electricity demand. This would mean that less electricity would have to be imported from Denmark or alternatively, that less non-hydro Norwegian electricity would be needed.

Example 2. Fertiliser:
In comparing agricultural (vegetable) products, the difference in fertiliser demand will affect the demand for (and thus the production of) artificial fertiliser while the production of animal manure will remain unaffected. The reason for this is that the production of the animal manure is constrained by the demand for the main products from the animal husbandry (meat and milk) which is even constrained by political limits (e.g. quotas). Thus, the (modern, unconstrained) artificial fertiliser production is the marginal technology to be applied in the comparison.

Example 3. Municipal Waste Water Treatment System: see example 2E in the SETAC WGI draft report.

C.3 Concluding statement

Definitions

The panel agreed upon the following definitions:

Constrained technology: A technology whose capacity cannot be expanded to the extent desired, *e.g.*, due to natural capacity constraints (*e.g.*, the amount of water available for hydro-power), political constraints (*e.g.*, no more nuclear power in Scandinavia, CO_2- or SO_2-limits), or the lack of a market for co-products (*e.g.*, co-generated heat).

Long-term: A period long enough to include replacement of capital equipment (as opposed to short-term).

Long-term marginal technology: The technology installed or dismantled due to foreseeable long-term changes in production volume.

Short-term marginal technology: The existing technology which changes its output due to small changes in production volume.

Most preferred technology: The most preferred technology is that with the lowest production costs per unit.

General statements

The following statements were agreed to with regard to the general choice of technological level:

Comparative studies

The following text relates only to comparative life cycle assessments.

The consequences of a comparative life cycle assessment is typically that a choice is made between different existing or potential product systems. Thus, it is the effects of this choice, which it is desired to investigate in the life cycle assessment. The technologies to study should be the technologies actually affected by the choice.

Ceteris paribus

The effects of this choice is normally regarded as being small compared to the production of society in general, which is therefore assumed to be unchanged. This means that the choice is analysed in isolation under a *ceteris paribus* condition. If the studied change is larger, it may be necessary to use other scenario techniques, which includes the necessary social changes.

Marginal technology

A choice between product systems will not affect all technologies equally. The technology actually affected is the marginal technology.

One should distinguish between short-term marginals, if the changes are not expected to affect capital investment (installation of new machinery or demolition of old machinery), and long-term marginals, where capital investment is affected.

Long-term

In most life cycle-assessments, the changes studied are assumed to affect capital investment. Therefore, in the following only long-term marginals will be discussed.

Identifying the marginal

If a specific unit process can be identified to be the one affected, and the actual conditions under which it will operate can be determined, then the specific data obtained from this unit process represents the marginal technology.

If a unit process delivering inputs to the rest of the product system through a market, and the unit process therefore cannot be described by site specific data, the technology involved depends on the current trends in the production represented by the unit process. If the production volume of the process is generally decreasing more than the average replacement rate for the capital equipment, the marginal technology will be the least preferred technology (typically old, non-competitive), and if the production volume of the process is generally increasing (or decreasing less than the average replacement rate for the capital equipment), the marginal technology will be the most preferred, unconstrained technology. Thus, if the general production volume of the process is generally decreasing at about the average replacement rate for the capital equipment, the marginal technology may shift back and forth from least to most preferred, which makes it necessary to make two separate scenarios.

If the production volume of the product system fluctuate in time, different sub-markets with their technologies (e.g. peak-load) may be relevant. If no fluctuations are found, the base-load marginal is the applicable technology.

Electricity production

For electricity production, the above general statements lead to the following recommendations for the specific study:

The electricity markets in Europe are still relatively protected, fragmented markets, which makes it necessary to determine the actual marginals in each market (country or production company) specifically. This needs further investigation and will be done as part of the project. It is not possible in advance to estimate if the result will be that the same technology is marginal in all markets.

It should be investigated as part of the project, whether the production volume of the product systems fluctuate in time, so that other marginals than base-load may be relevant.

Sensitivity analysis

A sensitivity analysis should be performed where all packaging systems are assumed to use the same technology for energy production (e.g. Nordic base-load marginal).

In-house electricity and heat production

In-house electricity and heat production should only be regarded as part of the analysed product system (with the credits this implies) if the energy would otherwise have been lost. This is the case for e.g. surplus heat from a thermal production process, or on-site incineration of production wastes or low value by-products. In most other cases, the energy production is a technically independent process, which could just as well be operated separately from the analysed production system, and thus should not be related to this.

Annex D:

Priority setting for data collection

Table D.1
Data collection strategy, showing the priority group for each process. Some of the processes in the table are aggregated, and include also upstream processes.

Data set	Priority	Comment
Key system parameters		
Primary packaging	1	Weight and composition
Secondary packaging	1	Weight and composition
Breweries	1	Annual consumption Major breweries Return rates bottles/crates
Littering rates	1	
Energy systems		
Electricity production	1	
Substitution from waste incineration	1	
Substitution from surplus heat production	1	
Recycling (inputs and outputs)		
PET recycling	1	
Cardboard recycling	1	
Aluminium recycling	1	
Production of flux for aluminium recovery	4	
Steel recycling	4	
PE recycling (screw tops)	4	
Distribution system	1	
Paper and cardboard production		
Cardboard production for trays	1	
Paper production for labels	2	
Production of kaolin and binder	4	
Glass bottles		
Glass and bottle production	1	
Sand production	4	
Scrap tinplate from other systems	4	
Broken glass from other systems	4	
Sulfuric acid production	4	
Soap production	4	
Tin production	4	

Continues on next page...

...Table D.1 continued from previous page:

Data set	Priority	Comment
Aluminium cans		
Bauxite production	1	
Primary aluminium production	1	
Can production	2	
Lid production	2	
Production of alloys	3	
Production of compounds for sealing lid	4	
Aluminium fluoride production	4	
Production of anode for aluminium	4	
Production of rolling oil	4	
Production of solvents	4	
Rinsing and filling	2	
Waste incineration	2	
Steel cans		
Can production	2	
Lid production	2	
Extraction of iron and production of primary steel	3	
Production of rolling oil	4	
Production of compounds for sealing lid	4	
Production of solvents	4	
Production of alloy materials	4	
PET bottles		
Primary PET production	3	
Stabilisers and additives	4	
Bottle tops		
Metal bottle tops	3	Scrap content Tin content
Production of metal bottle tops	4	
Raw materials for metal bottle tops	4	
Production of PE screw tops	3	
Primary PE production (for screw cap)	4	
Stabilisers and additives	4	
Aluminium foil neck cover for glass bottles	4	
General materials		
Crude oil extraction and refining	1	Including feedstock for PET
Glue for labels	3	
Printing ink and colours for labels	3	
Sodium chloride production	4	
Sodium hydroxide production	4	
Natural gas	4	
Coal	4	
Limestone/Lime production	4	
Colours, stabilisers, additives for crates	4	
Lacquer and colour for cans	4	

Continues on next page...

...Table D.1 continued from previous page:

Data set	Priority	Comment
Use: refrigeration	3	
Retail	3	System interactions Machinery
Transport scenarios except distribution	3	
Production of crates	4	
Hi-cone	4	
Production of pallets	4	
Waste water treatment	4	

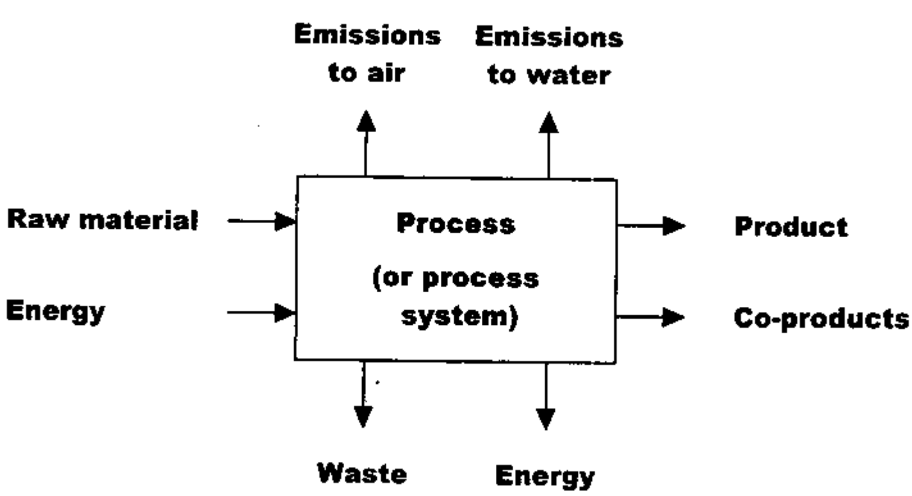
Annex E:

Data questionnaire and instructions for data suppliers

Introduction

Life Cycle Assessment (LCA) is a method for calculating the environmental loadings (inputs and outputs) caused by a product or system and evaluating the environmental impact from these loadings. The assessment encompasses the entire life-cycle of the product; that is from the mining, forestry, etc., where the material in nature is taken into the industrial system, to the final disposal or recovery of the material. Environmental loadings are represented by the use of natural resources, emissions to air, water and soil as well as waste.

In order to calculate the total environmental loadings during the whole life-cycle, data on raw material and energy use, transports, etc. from each process is needed. The basic principle is then that each "box" (see figure below) should contain one process. In many cases a production process involves many steps or processes. When data are available for each of these process steps we prefer to present them separately i.e. non-aggregated. In reality this is often not possible and in this case aggregated data for the system of processes has to be presented.



Data sheets

For each process (or process system) we would like you to use the attached data sheets (inflows and outflows) for filling in the relevant data. Please copy the data sheets in as many copies as you have processes.

We would like you to specify all parts where data are missing, and for which reason. We would also prefer that you write down all assumptions made when collecting and calculating your data. State if any data are confidential, and to what extent. Data will be treated confidential if you wish so.

When filling in the data please follow **the *checklist* below**.

Data sheet checklist

The following information is required:

Inflows

1. Company name and the geographical location (e.g. city, region or country).
2. Person responsible for data set (name and telephone number).
3. Process description: Where the reported process begins and ends, the technology used, and if the data includes:
   - Cleaning
   - Maintenance
   - Research and development
   - Laboratory facilities
   - Marketing
   - Administration
   - Facilities for the personnel (heating, lighting, working clothes, canteen, toilets)

   If not included, such data should preferably be given separately (on separate data sheets).

4. The *reference product* is to be considered as the product for which we require data. You may write e.g. 1000 kg here. Then the data in the inflows and outflows data sheet should all refer to 1000 kg of the reference product. You may also use the actual production figure for a specific time period (e.g. for a certain year). If you produce several different products (or co-products) in the same process as the reference product, please specify the amount of these other products in the outflows data sheet (see no 8).

5. The time period for which data are valid. Please note whether the production is stable over the year/week/day or if it fluctuates with highs or lows in specific seasons, specific days of the week or specific times of the day.

6. Raw materials and auxiliary materials
   Specification of the amount of *raw materials used* in each step, as well as *auxiliary materials* or aiding compounds e.g. the kind and amount of solvents. The unit (kg, m3 etc. per reference unit) should be noted in the column head or after the actual figure.

   If possible we would like to know the variation of data, for instance the minimum and maximum value during the time period that the given data represent (only for auxiliary materials).

   For each material the *supplier* company and site of supplier (city, country).

   Transport data: internal transports (if there are any) and transports of materials to your process. The transport data needed is: which material that is transported, the transport mode (long or short distance truck, tanker, boat or train (electricity or diesel)), the distance one way (km) (or between which cities it is transported) and if there is an empty return trip or not. If possible we would like to know the maximum load of the vehicle and average load of the specific transport. If more details are available such as type, capacity or energy consumption of the vehicle, this may as well be stated here (on a separate paper, if not enough space).

7. The energy used should be specified as:

- Electricity consumption from the net [kWh per reference unit]
- Electricity consumption from own production [kWh per reference unit]
- Fossil fuel consumption [kg or m3 per reference unit, with indication of size and type of heater/boiler]:

  - Oil (specify class and sulphur content)

  - Diesel oil (for trucks etc., specify class and sulphur content)

  - Coal (specify which coal)

  - Natural gas (specify composition such as content of methane if possible)
- Use of district heat or other heat from an external source (if used for other purposes than heating of buildings) [MJ per reference unit]
- Others [MJ per reference unit]

Variation of data is described under 6.

The electricity consumption might be based on either measurements or derived from the nominal power of the machine/oven respectively, with an assumption of the working power (Watt) and time used for the actual product. Please show how you have made the calculations. There is a field *"Measurement/calculation method, number of measurements made"*, in which such issues could be described.

Under Energy use you may also present *energy production* if there is a net production of energy in the process (for instance steam or heat). In this case please note how this energy is used.

Outflows

8. Co-products

If the data you present is valid for several products we would like you to specify the amounts of these other products (and co-products, if relevant) in the outflows data sheet. Co-products are defined as any material or energy which leaves the process and for which there is a positive economic value to you (the opposite to waste). The unit (kg, m^3 etc. per reference unit) should be noted in the unit column. When m^3 is used please specify the density.

9. Emissions to air

   For combustion of fuels please specify the emissions of CO_2, CO, NO_x, SO_2, Non-Methane-VOC (Volatile Organic Carbons), CH_4 (methane), N_2O, Particles (please specify sizes and composition, if possible) and Others. If there are metal emissions, please specify which type e.g. Hg, Pb, Cu etc. Emissions from combustion of fuels should, whenever possible be kept separate from process emissions (e.g. from the use of paint and organic solvents). A description of the origin of data should be included (if emissions are measured or calculated etc.). The unit (gram or kg etc. per reference unit) should be noted in the unit column.

10. Emissions to water

    Water emissions to waste water treatment as well as to the water recipient from the water treatment (if there are any). If there are metal emissions, please specify which type e.g. Hg, Pb, Cu etc. The unit (gram or kg etc. per reference unit) should be noted in the unit column.

11. Emissions to soil

    The leakage from the process, stocks, deposits, etc. to soil. The unit (gram or kg etc. per reference unit) should be noted in the unit column.

12. Waste

    The waste produced in each step, including the weight and final treatment (waste treatment method and company) of each type of waste. Please specify waste treatment method as well as transport mode and transport distance for the transportation of waste to the waste treatment. The unit (kg, m^3 etc. per reference unit) should be noted in the unit column. When m^3 is used please specify the density.

13. Transport of the reference product

    For the transportation of the reference product to your customer please specify the transport mode, distance one way and if there is and empty return trip or not.

Please do not forget to specify units for all parameters. When m3 is used please specify the density.

When, for instance the process description field, the comments fields etc. are too small, please use a separate paper in order to present the information. You may also enclose copies of specification sheets for raw materials and auxiliary materials, as well as copies of measurement reports etc. If you are at any time in doubt about how to fill in the data sheets, **please do not hesitate to phone us or send us a fax.**

Company:

Main product:

Process description (separate if not enough space):

Person responsible for data set:

Data from time period:

Data given for produced unit:

RAW MATERIAL	QUANTITY	Variation of data	SUPPLIER		TRANSPORT	Distance one way	EMPTY	COMMENTS
specification	(e.g.kg/year or	(minim. and max. value)	Company	Site (city, country)	Vehicle, max load weight	(km)	RETURN	
	kg/production unit)				and average load		(Yes/No)	

AUXILIARY MATERIALS	QUANTITY	Variation of data	SUPPLIER		TRANSPORT	Distance one way	EMPTY	COMMENTS
specification	(e.g.kg/year or	(minim. and max. value)	Company	Site (city, country)	Vehicle, max load weight	(km)	RETURN	
	kg/production unit)				and average load		(Yes/No)	

ENERGY USE	QUANTITY	UNIT	Variation of data		Measurement method, number of measurements/calculations made			
			(minim. and max. value)					
Electricity								
Oil (specify)								
Diesel (specify)								
Natural gas								
Coal								
Renewable fuel (specify)								
Other (specify)								

Company:	Main product:
Person responsible for data set:	Data from time period:

PRODUCTS AND CO-PRODUCTS if relevant					
Product name	**QUANTITY**	**UNIT** (e.g.kg/year)	**Variation of data** (minimum and maximum value)	**Degree of confidentiality**	**Other comments**
AIR EMISSIONS	**QUANTITY**	**UNIT** (e.g. g/year)	**Variation of data** (minimum and maximum value)	**Degree of confidentiality**	**Measuremetn method, number of measurements**
CO2					
CO					
NOx					
SO2					
HC					
VOC (please specify)					
CH4					
dust					
particles			specify particle sizes and composition		
Other (specify)					

Company:			Main product:		
Person responsible for data set:			Data from time period:		
WATER EMISSIONS	**QUANTITY**	**UNIT**	**Variation of data**	**Degree of**	**Measurement method,**
To recipient		**(e.g. g/year)**	(minimum and maximum value)	**confidentiality**	**number of measurements**
COD					
BOD					
Tot-N					
Tot-P					
Other (specify)					
WATER EMISSIONS					
To waste water treatment					
COD					
BOD					
Tot-N					
Tot-P					
Other (specify)					
WASTE	**QUANTITY**	**UNIT**	**Variation of data**	**Waste treatment**	**Transportation distance**
		(e.g. kg/year)	(minimum and maximum value)	**method**	**and transportation mode**
Hazardous (specify)					
Other (specify)					

Annex F:

The EDIP method for life cycle impact assessment

F.1 Characterisation

Impact potentials

The impact potentials for the product are the sums of the impact potentials for the emissions occurring throughout the product system. Whether the potentials trigger actual effects depends inter alia on how the emissions occur and the concentrations of substances to which they contribute in the environment. These conditions are rarely known in product LCAs.

Calculation of the potential contributions from an emission to an environmental impact requires a knowledge of how strongly the substances emitted contribute to the type of environmental impact in question.

Equivalency factors

The substance's impact potential is expressed in the form of an equivalency factor. The equivalency factor expresses the substance's strength measured relative to a reference substance, and this method of expressing the equivalency factor is common for most categories of environmental impacts. For example, for global warming the reference substance is carbon dioxide, CO2, and the equivalency factors thus express the substances' potential impacts as grams of CO2 equivalent per gram of substance. When methane has an equivalency factor of 25, it means that emission of 1 gram of methane contributes as much to global warming as the emission of 25 g CO2.

Substances which can contribute to more than one category of environmental impact have an equivalency factor for each impact category.

F.2 Normalisation

In comparing potential impacts from alternative products, one alternative will sometimes prove to have a lower contribution to all impact potentials than the other. The calculation of impact potentials has thus fulfilled a significant objective, as it is now clear which alternative is preferable from an environmental perspective. However, it will often be such that one alternative has the lowest impact potentials for certain impact categories, while the other has the lowest impact potentials for other impact categories. In this situation, the various impact potentials must be assessed relative to each other. Are any of them greater and more serious than others? To be able to compare the environmental impacts from different products or activities, it is useful to compare them against a common reference. This is the object of normalisation. In normalisation, the impact potentials are compared with an impact which is common for all impact categories, and of which the consequences for the environment are known. In this way an impression is gained of which potential impacts are large and which are small, seen in relation to the known reference impact.

As normalisation references, the EDIP method uses the potential impacts which society imposes on the environment in one year. Even if some of the future consequences of society's current impact on the environment are unknown, we still have an idea of how serious the situation is for each individual impact category, and this knowledge is used in the subsequent weighting.

Global/Danish references

For global impacts, the potential contribution to the impact is as big wherever in the geography the emission occur. However, for regional and local impacts only emissions and resource depletion occurring within the region or local area in question contribute to the current and future condition of the environment in the region or local area respectively. Emissions of greenhouse gases thus contribute to global warming irrespective of where in the world they occur. But emissions of substances in the Far East or North American which can contribute to acidification have no influence on the level of acidification of forests and lakes observable in Europe today.

The normalisation should provide a good basis for the subsequent weighting. The weighting is based on political decisions on reduction targets (see below). Therefore it is important that the impacts used as a normalisation reference corresponds to the geographical level on which the effects are perceived. For the regional impacts the global impact levels are of little relevance. Emissions of SO2 in the Far East have no influence on the acidification that is perceived in Scandinavia or Europe.

The difference between using Danish or European normalisation references in the EDIP method has been investigated for photochemical ozone formation and acidification. The difference is not significant for these impact categories.

On this basis, the normalisation and the subsequent weighting should ideally be carried out with normalisation references and weighting factors which, for each individual emission, are representative of the region where the emission is occurring. As default values, the EDIP method uses Danish normalisation references and weighting factors based on Danish environmental policy for the regional and local environmental impact categories. Global references are used for global impacts such as global warming.

The person-equivalent

The global impact will always be much greater than the impact from a particular region, irrespective of the type of effect to which the impact contributes. Use of global impacts as normalisation reference for the global impact categories and regional impacts for the regional and the local impact categories will thus give an imbalance in the normalisation, and it will result in global impacts from the product system coming to appear much less than the other impacts, because they are compared with the activity of the population of the entire world, while the others are compared only with the activity of, *e.g.*, the Danish population.

To correct this bias and ensure that the set of normalising references constitutes a more common scale for all impact categories, irrespective of whether they are global or regional, the normalisation references are calculated as the background impact over the course of one year per person in the area for which the impact is computed. This gives the normalisation references the unit "impact potential per person per year" for each individual impact category. The unit is abbreviated PE (person equivalents).

PE_{WDK90}

To be more precise, the normalised results are expressed in the unit PE_{WDK90}, because they refer to an average person in the world (W) or in Denmark (DK), and because the EDIP method currently operates with 1990 as reference year for normalisation.

All potential impacts thus assume the same unit, and it is possible to compare their magnitudes. At the same time, the normalised potential impacts of the product are expressed in a comprehensible unit as they can be viewed relative to one's own average contribution to the impact. It is now possible to compare the relative magnitude of the contributions from alternative products to the individual impact categories.

F.3 Weighting

Even if it becomes clear with normalisation which contributions are large and which are small relative to the background load, there will always be situations where judgement is required in comparison of alternative products, where one alternative has the lowest normalised impact potentials for some impact categories, while another alternative contributes least to others. In such a "trade-off" situation, the various impact categories must be weighted relative to one another before they can be compared. Are some of them more serious than others, and how much more serious?

Normalisation assists in assessing which of the potential impacts are large and which are small, by placing them in relation to the impacts from an average person in 1990. But even if the potential impacts for two different impact categories are equally large on normalisation, this does not automatically mean that the two potential impacts are equally serious. To be able to compare the potentials for the various impacts, an assessment must first be made of the seriousness of the impact categories relative to one another.

The mutual seriousness of the impact categories is expressed in a set of weighting factors with one factor per impact category.

Political targets

The EDIP method seeks to fix the weighting factors so that they reflect the official societal priorities as well as possible. This is achieved by using political environmental targets within the field of each individual impact category as a basis for the weighting.

The authorities' regulation of society's impact on the environment has focused on those activities which have the greatest environmental impacts. International agreements and national plans of action have set reduction targets for society's impacts on the environment. Today there are thus politically determined targets for reductions in the most significant contributions to all of the impact categories treated by the EDIP method.

When targets are set for reductions in society's environmental impact, this is based on considerations of how serious the consequences of the impact can be, and the costs which will be associated with reducing them. The considerations include such issues as:

- What damage to the environment can be observed today as a consequence of the impact?
- What damage to the environment can be expected as a consequence of the impact, and what environmental consequences can result in the short and the long term?
- What costs will this damage impose on society?
- What technological possibilities are available for preventing and repairing the damage?
- Is the public aware of the environmental effect?
- How will the planned measures against the impact affect the national and the international economies and employment?

As a rule, scientific research on an environmental effect has been going on for a long time before plans of action are initiated or targets for reduction adopted. Plans of action and targets for reductions thus usually have a substantial scientific background.

For the individual environmental impact category, the political setting of reduction targets therefore implies a balancing of scientific, technical and political considerations. No conscious balancing of the seriousness of this environmental impact is made relative to the seriousness of the other impacts to which the environment is exposed. But the targets for reductions are set within society's total economic frame for environmental improvements, and the initiative regarding individual substances and groups of substances is therefore indirectly ranked in relation to the total environmental measures. On this basis, the political setting of reduction targets can be considered a result of a decision-making process similar to that which should underlie the determination of weighting factors for the environmental impact categories.

The situation is such that the authorities have set reduction targets for the most significant of the emissions which contribute to the impact categories entering into the EDIP method. Many authorities desire a product-oriented environmental policy as a central part of their environmental administration, and thus as a significant means of achieving the reduction targets which have been set.

This argues strongly for determining the weighting factors on the basis of political reduction targets. The authorities will not be able to defend environmental priorities for the product policy other than those which can be deduced from the reduction targets, for in such case the reduction targets from action plans, agreements etc. and the product-oriented environmental policy will pull in different directions. But by using this way of determining weighting factors, the authorities have a powerful instrument to ensure that companies have the correct environmental priorities when developing new products. If the societal reduction targets are changed for certain impacts, the changes can be transferred accordingly to the corresponding weightings in the product-oriented environmental policy. The weighting factors must therefore be adjusted at intervals, for example every fifth year together with the normalisation references, to keep them in accordance with the current reduction targets.

Danish targets

In determination of weighting factors for the individual impact categories, the EDIP method is based on the existing Danish political targets for reduction of various categories of environmental impacts.

Political targets for reductions are normally set for individual substances or groups of substances and not for total contributions to environmental impacts. For example, there is a target in many countries for reduction of society's emissions of CO2, which is the most significant greenhouse gas, but not for a reduction in society's total contribution to the global warming impact, which is also attributable to substances other than CO2. The reduction targets for individual substances can, however, be translated into reduction targets for environmental impacts with the aid of the equivalency factors in the same way that the inventory of emissions and consumption of resources for a product system can be translated into environmental impact potentials.

As a rule, the reduction targets are formulated such that society's emissions of a substance or a group of substances in the selected target year may amount at most to a certain percentage of the emissions in a reference year. But reference year and target year vary for the various substances and groups of substances, depending on the time when the reduction targets are set, and also on the desirable and realistic time frame for achievement of the reductions.

To give a uniform treatment of all environmental impact categories, the reduction targets are harmonised in the EDIP method to apply to the same period for all environmental impact categories before they are used as a basis for calculation of the weighting factors.

Target year 2000

The year 2000 was chosen as the common target year, while 1990, the normalisation references' inventory year, was chosen as the common reference year.

Interpolation/extrapolation

Actual political decisions state target levels at different years. The political decisions that form the basis for our weighting factors state target levels as soon as 1998 or as late as 2010. To derive the weighting factor, an estimate is made of the magnitude of the target emission if the target year had been 2000. The estimate is made by linear interpolation if the actual target year is beyond 2000 and by linear extrapolation if the target year is before 2000.

The weighting factor is derived as the quotient between the impact level at the reference year and the (estimated) target level at the year 2000. The weighting factor thus expresses by how much the normalisation reference must be reduced by the year 2000 to be in accordance with the efforts expressed by the reduction targets for the environmental impact in question. The sharper the reduction targets, the greater the weighting factor for the environmental impact.

The choices of target year, reference year and method of interpolation are not objective. They could be selected differently, and this will be of significance for the relative magnitudes of the individual weighting factors. The target year must, however, lie a suitable number of years in the future, so that the weighting factors provide a certain assurance of how the impact categories will be ranked relative to one another when the product eventually enters the market.

The weighted environmental impact potential for the product is equal to a percentage of the person-equivalent which can be expected in the year 2000 if society's plans for reduction are achieved.

$PET_{WDK2000}$

The unit is $PET_{WDK2000}$, which stands for person-equivalent based on target emissions in the year 2000. WDK stands for the weighting of global impact categories on the basis of the accepted global contributions in the year 2000, while the regional and the local impact categories are weighted on the basis of the accepted contributions in Denmark. The word "accepted" should not be taken too literally. It is not supported by statutory requirements, but by national and international conventions and plans of action for the extent of reductions by the year 2000.

References

Further information is given in Wenzel *et al.* (1997) where also the actual values used in Wesnaes (1996) are derived and presented. For the scientific background, see Hauschild & Wenzel (1998)

F.4 New toxicity factors

Compared to Wesnaes (1996), new values have been developed for the equivalency factors for toxicity. The new values are shown in Table F.1. Also the normalisation and weighting factors for toxicity have been updated according to Wenzel et al. (1997). These are presented in Table F.2.

Table F.1

Equivalency factors for toxicity according to the EDIP method (Wenzel et al. *1997).*

	Ecotoxicity				Human toxicity			
First receiving media	*Emissions to air*		*Emissions to water*		*Emissions to air*			*to water*
Impact category	*Water, chronic*	*Soil, chronic*	*Water, chronic*	*Water, acute*	*Air*	*Water*	*Soil*	*Water*
Substance	(m^3/g)	(m^3/g)	(m^3/g)	(m^3/g)	(m^3/g)	(m^3/g)	(m^3/g)	(m^3/g)
1-butanol	$1.5\cdot10^{-2}$	$9.2\cdot10^{-2}$			$1.3\cdot10^{4}$	$1.4\cdot10^{-3}$	0.14	
2,3,7,8-tetra-chlorodibenzo-p-dioxin	$5.6\cdot10^{8}$	$1.2\cdot10^{4}$			$2.9\cdot10^{10}$	$2.2\cdot10^{8}$	$1.4\cdot10^{4}$	
Antimony					$2.0\cdot10^{4}$	64	17	
Arsenic	$3.8\cdot10^{2}$	0.3	$1.9\cdot10^{3}$	$1.9\cdot10^{2}$	$9.5\cdot10^{6}$	7.4	$1.0\cdot10^{2}$	37
Benzene	4							
Cadmium	$2.2\cdot10^{4}$	1.8	$1.2\cdot10^{5}$	$1.2\cdot10^{4}$	$1.1\cdot10^{8}$	$5.6\cdot10^{2}$	4.5	$2.8\cdot10^{3}$
Carbon monoxide					$8.3\cdot10^{2}$			
Chlorine					$3.4\cdot10^{4}$			
Copper	$2.5\cdot10^{3}$	$1.8\cdot10^{-2}$	$1.3\cdot10^{4}$	$1.3\cdot10^{3}$	$5.7\cdot10^{2}$	3.4	$4.0\cdot10^{-3}$	17
Hydrogen cyanide	$8.0\cdot10^{2}$	$7.6\cdot10^{3}$	$8.0\cdot10^{2}$	$2.0\cdot10^{3}$	$1.4\cdot10^{5}$	$1.5\cdot10^{-3}$	0.71	$1.5\cdot10^{-3}$
Hydrogen sulphide	$1.3\cdot10^{3}$	0	$6.7\cdot10^{3}$	$3.3\cdot10^{3}$	$1.1\cdot10^{6}$	$8.1\cdot10^{-4}$	0	$4.1\cdot10^{-3}$
Iron					$3.7\cdot10^{4}$			
Lead	$4.0\cdot10^{2}$	$1.0\cdot10^{-2}$	$2.0\cdot10^{3}$	$2.0\cdot10^{2}$	$1.0\cdot10^{8}$	53	$8.3\cdot10^{-2}$	$2.6\cdot10^{2}$
Mercury	$4.0\cdot10^{3}$	5.3	$4.0\cdot10^{3}$	$2.0\cdot10^{3}$	$6.7\cdot10^{6}$	$1.1\cdot10^{5}$	81	$1.1\cdot10^{5}$
Nickel	$1.3\cdot10^{2}$	$5.3\cdot10^{-2}$	$6.7\cdot10^{2}$	67	$6.7\cdot10^{4}$	$3.7\cdot10^{-3}$	0.12	$1.9\cdot10^{-2}$
Nitrogen dioxide					$8.6\cdot10^{3}$			
Phenol			44	22				
Selenium	$4.0\cdot10^{3}$	63			$1.5\cdot10^{6}$	28	$2.6\cdot10^{-2}$	
Silver					0.27			
Toluene	4							
Xylenes, mixed	4	0.40			$6.7\cdot10^{3}$	$1.1\cdot10^{-3}$	$6.7\cdot10^{-5}$	
Zinc	$2.0\cdot10^{2}$	$5.3\cdot10^{-3}$	$1.0\cdot10^{3}$	$1.0\cdot10^{3}$	$8.1\cdot10^{4}$	4.1	$1.2\cdot10^{-2}$	21

Table F.2
Normalisation references and weighting factors for toxicity according to the EDIP method (Wenzel et al. *1997).*

	Ecotoxicity			Human toxicity		
	Water, chronic	*Water, acute*	*Soil, chronic*	*Air*	*Water*	*Soil*
Normalisation reference (m^3/person/year)	$4.7 \cdot 10^5$	$4.8 \cdot 10^4$	$3.0 \cdot 10^4$	$9.3 \cdot 10^9$	$5.9 \cdot 10^4$	$3.1 \cdot 10^2$
Weighting factor	2.6	2.6	1.9	2.8	3.1	2.3

Annex G:

Hearing group members

G.1 Hearing 1

In the first hearing round, the hearing group consisted of the companies which had notified that they would participate in the study as well as some additional companies and interest organisations. Table G.1 includes the contacted data suppliers and table G.2 shows the additional companies and organisations. These were given the opportunity to comment on a draft copy of the report from the pre-project, including the screening of the previous study and an initial definition of goal and scope.

Table G.1
Data suppliers which were contacted to be members of the hearing group.

Name	Area	Country
Altoplast A.G.	Reichenburg	Schweiz
AMG Resources Ltd.	Birmingham	England
APEAL (Association of European Packaging Steel Producers)	Brussels	Belgium
Betts Company Plastics	Essex	England
Boliden Intertrade Inc.	Atlanta, Georgia	USA
Bryggeriforeningen	Copenhagen	Denmark
Bryggerigruppen A/S	Aarhus	Denmark
Carlsberg A/S	Copenhagen	Denmark
Carlsberg A/S	Valby	Danmark
Coca Cola Company	Atlanta	Georgia, US
Coca-Cola Danmark A/S	Glostrup	Denmark
Coca-Cola Nordic and Northern Eurasia Division	Lysaker	Norway
Constar International Holland B.V	Didam	The Netherlands
Continental PET Deutschland Gmbh - Schmalbach Lubeca PET	Ratingen	Germany
Continental PET Deutschland Gmbh - Schmalbach Lubeca PET	Ascoli Piceno	Italy
Dadeko A/S	Glostrup	Denmark
Dansk Systemmørtel A/S	Karlslunde	Denmark
Danske Læskedrik Fabrikanter	Copenhagen	Denmark
Dynoplast	Stjørdal	Norway

Continues on next page...

...Table G.1 continued from previous page:

Name	Area	Country
Eastman Chemical International A/S	Taastrup	Denmark
Faxe Kalk	Copenhagen	Denmark
Gränges AB	Finspång	Sweden
Hoechst Danmark A/S	Rødovre	Denmark
Holmegaard Glasværk	Næstved	Denmark
Inco Europe Ltd.	London	England
Jan de Poorter bV	Geertrindenberg	The Netherlands
Johnson Control Plastics SpA	Loreto	Italy
Johnson Controls International	Brecht	Belgium
Larsen og Becher A/S	Køge	Danmark
Nancanco	Luton	England
National Starch and Chemicals A/S	Tølløse	Denmark
Nova-Print AS Danmark	Odense	Denmark
PLM (Can Division)	Malmö	Sweden
PLM Environmental Affairs GHQ	Malmö	Sweden
PLM Holmia A/S	Kolding	Denmark
PLM Lidköping AB	Lidköping	Sweden
Rasselstein Hoesch GmbH	Neuwied	Germany
Reffakt		
Schoeller-Plast-Enterprise A/S	Regstrup	Denmark
Shamokin Filler	Pennsylvania	USA
Sollac	Paris la Défense	France
Svenska Returpack AB	Stockholm	Sweden
Tomra Systems A/S	Ishøj	Denmark
Tuborgs Bryggeri A/S	Copenhagen	Denmark
Wellman Fibres Ltd	West Yorkshire	England
Wellman International Handelsgesellschaft GmbH.	Dortmund 70	Germany
Wellman International Ltd	Co. Mearth,	Republic of Ireland
Wellman Recycling BV	Spijk	The Netherlands

Table G.2
Members of the hearing group, additional to those listed in table B1.

Organisation	Location	Contact person
Miljöbalans AB	Bjärred, Sweden	Gustav Sundström
NOAH - Friends of the Earth Denmark	Copenhagen, Denmark	Carsten Pedersen
Greenpeace Danmark	Copenhagen, Denmark	
Danmarks Naturfredningsforening	Copenhagen, Denmark	Poul Henrik Harritz
Dansk Handel og Service	Copenhagen, Denmark	Charlotte Bill
Plastindustrien i Danmark	Copenhagen, Denmark	Jette Rasmussen
Emballageindustrien	Copenhagen, Denmark	John Niklasson
The Danish Consumer Counsil	Copenhagen, Denmark	Thomas Breck
Fællesforeningen for Danmarks Brugsforeninger	Albertslund, Denmark	Mogens Waerge

G.2 Hearing 2

In the second hearing round, the hearing group consisted of companies which had delivered key data to the project plus some additional companies and interest organisations (Table G.3). These were given the opportunity to comment on drafts of the goal definition in the main report, the Technical report 7 and the LCAs of one or more of the individual systems (Technical reports 1-6).

Table G.3
Hearing group members in the second round.

Name	Area	Country
AMG Resources Ltd.	Birmingham	England
APEAL (Association of European Packaging Steel Producers)	Brussels	Belgium
Bryggeriforeningen	Copenhagen	Denmark
Bryggerigruppen A/S	Aarhus	Denmark
Carlsberg A/S	Copenhagen	Denmark
CASCO Nobel	Stockholm	Sweden
Dadeko A/S	Glostrup	Denmark
The Danish Consumer Council	Copenhagen	Denmark
Danmarks Naturfredningsforening	Copenhagen	Denmark
Dansk Supermarked	Højbjerg	Denmark
Emballageindustrien	Copenhagen	Denmark
European Aluminium Association	Brussels	Belgium
Friends of the Earth Denmark	Copenhagen	Denmark
Fællesforeningen for Danmarks Brugsforeninger	Albertslund	Denmark
Greenpeace Danmark	Copenhagen	Denmark
Gränges AB	Finspång	Sweden
Holmegaard Glasværk	Næstved	Denmark
Miljöbalans AB	Bjärred	Sweden
PETCORE	Harrogate	UK
Plastindustrien i Danmark	Copenhagen	Denmark
PLM (Can Division)	Malmö	Sweden
PLM Environmental Affairs GHQ	Malmö	Sweden
PLM Lidköping AB	Lidköping	Sweden
Rasselstein Hoesch GmbH	Neuwied	Germany
Schmalbach-Lubeca AG	Ratingen	Germany
Schoeller-Plast-Enterprise A/S	Regstrup	Denmark
Svenska Returpack AB	Stockholm	Sweden
Tomra Systems A/S	Ishøj	Denmark
Wellman Inc.	Charlotte	USA

Annex H:

Critical review of LCA on packaging systems for beer and soft drinks

H.1 Introduction

An independent external expert was selected by the commissioner of the study to be chairperson of a critical review panel.[1] The chairperson selected in addition four other independent external experts for the panel. The members were chosen in accordance to their experience in the LCA and packaging field, and they were approved by the commissioner.

Panel members
The members of the critical review panel were:

- *Allan Astrup Jensen* (chairperson), and *Anders Schmidt*, dk-TEKNIK Energy and Environment, Denmark
- *Ivo Fecker* and *Ruth Förster*, EMPA[2], St. Gallen, Switzerland
- *Dennis Postlethwaite*, LCA consultant[3], Merseyside, UK.

Review phases
The critical review was divided in three phases:

1) Evaluation of Report A: Definition of goal and scope - result of the preliminary investigation,
2) Evaluation of the first draft Main Report (without comparisons) and technical reports,
3) Evaluation of the final (draft) Main Report (with comparisons) and technical reports - before final changes.

For each of the phases a critical review report with detailed comments and suggestions was produced.

[1] Kontrakt mellem dk-TEKNIK og Miljøstyrelsen om gennemførelse af critical review på opdatering af livscyklusanalyse af emballage til øl og læskedrikke, 23 juni 1997, J.nr. M 3048-0011
[2] Eidgenössische Materialprüfungs- und Forschungsanstalt
[3] Formerly served as LCA co-ordinator at Unilever and chairman of the SETAC-Europe LCA Steering Committee

Members of the panel met with the LCA practitioners and DEPA on 4th July 1997, 6th February 1998 and 30th March 1998 and discussed the draft project reports in light of the detailed critical review reports. Most comments from the Panel were either accepted by the study team or withdrawn.

Tasks of the panel

The main efforts of the critical reviewers have been to check in the different phases of the work:

- whether the reports were consistent, transparent, understandable, did not include errors and the conclusions drawn could be justified with the database and methodology used in the project.
- whether comments made in the earlier review reports have been addressed by the project team in the proceeding phases of the work.

Thereby, the reviewers considered the ISO 14040:1997 standard and the LCA Code of Practise given by SETAC (1993). Further, the reviewers have suggested improvements, especially regards clarifications in the text.

Review period

This external critical review was conducted in the period from June 1997 and to March 1998. That means that the panel has not evaluated later changes of the final report and its conclusions.

The LCA study and the critical review had to be performed within a relatively short period of time and a somewhat limited budget. Further, the number and size of the reports were large, and there were delays in receiving some of the reports. It was therefore impossible, to look in detail at every technical report and appendix, and to check all data. Some spot check of the data were performed. In order to cover as many reports as possible some tasks had to be divided between the review panel.

H.2 General comments

Consistency with ISO 14040 and common practise
The study follows the LCA-steps and principles according to ISO 14040ff series. The chosen methods are sound and recognise standards or common practise (ISO, SETAC). It is explicitly mentioned within the study where ISO-standards could not be followed or applied for a given reason. The main processes of the work, notably goal and scope definition/boundary setting, inventory compilation and the first stages of impact assessment (specifically, classification; characterisation; normalisation) have been undertaken very thoroughly.

Transparency
It is admirable that is has been possible to perform this extensive and impressive study with relatively little delay, taking into consideration the numerous pitfalls and sources of potential errors that are possible in a study of this nature.

Overall transparency of the study can be judged as high as the time limitations of the project allow it and is adequate to the common practise in LCA. At the same time, the reviewers would like to point out that the transparency of the study of the single systems is rather limited despite the fact that many efforts have been devoted to explanation of specific LCA-issues. This criticism is not directed against the project team but is a general concern for the requirements of a LCA to be used as support of public decision making.

Reporting of results
In general, the reports are well written, using a clear understandable language in most of the sections. Some parts of the reports, however, are very technical and require a detailed knowledge of specific elements, which are normally outside the scope of a general LCA-report.

There is one overall criticism that is important. It applies to many LCA's and, as such is a fundamental problem. The study has generated a massive amount of data and information, which, as is very obvious, is difficult to interpret, assimilate and comprehend. This is a current weakness of the LCA approach. There is a vital need to collate, condense and consolidate the information generated such that it is comprehensible, especially to the study commissioners and key report recipients, and in which the findings of significance are distilled out and highlighted in a proper context.

Communication
Concerning this study the long list of individual comparisons may possibly be useful to those readers who are experts on LCA or specific systems, the more general reader, and certainly those not well versed in the LCA technique, will likely have neither the interest nor the stamina to read and study the comparisons and conclusions as they were presented in the final draft report, although they may well need some of the information embedded within them. Thus, what would be very useful, and is essential for the communication of the results, is a good summary of the main conclusions, especially of the significant differences and comparisons. It is a critical requisite that key recipients of the study, notably decision-takers and the commissioners themselves, are able to assimilate *and usefully employ* the results and findings of the study.

Interpretation
There is a good approach to interpretation and the use of sensitivity analyses to probe key issues, and dominance analysis to determine major differences is exemplary, although the reservations made above on this deserve recognition. It may be difficult to get a clear overview.

The sheer number of comparisons and conclusions presented precluded full and detailed assessment within the resource (time) limits of the critical review. However, random inspection indicates that most conclusions have been properly drawn. They appear to be fairly based on the inventory and impact assessment data and to cover all relevant issues. Additionally, most, if not all, are very transparent, rendering it possible for any recipient of the reports to check, and challenge if necessary, individual conclusions and analyses. Overall, the translation of results from the data sections to the interpretation appears to have been conducted with commendable thoroughness and without any obvious bias.

Significance of results
There is an issue concerning the significance of the results and the comparisons. This could possibly have been better addressed. In particular, some indication of which differences are (1) Highly significant (*i.e.* definitely different); (2) Significant (*i.e.* probably different); and (3) Non-significant (*i.e.* unlikely to be different/not measured with sufficient accuracy) is required to help interpret and understand the results. This should follow established protocol, for example, that which requires a difference between results of 10% for energy and 20% for the other environmental parameters for them to be considered significantly different. A consideration of significance could help quantify the comparisons and establish rank orders, thereby going some way to address and resolve the main criticism made in above.

Representativity
A clear indication must be given in the report of the representativity of the data and results. This needs to be done for each of the systems studied and should state what proportion of actual practice the results represent and whether it is realistic to extrapolate the data obtained to the total market situation. To this end, a small table presenting the collated representativities could usefully be incorporated in the summary report. Representativity is an important consideration in any LCA, and its omission from the present study could be construed as a weakness.

Limitations
The purpose of the study was to provide an objective base, specifically information and data, for deciding which of the beverage packaging systems is environmental preferable. To fulfil this, the predictive power of the LCA approach needs to be balanced and assessed against the inherent uncertainties. For this, it is essential to consider the limitations, particularly any omissions of the study, and to assess its validity.

H.3 Specific comments

Inventory tables
The many inventory tables contain an enormous amount of single data, which is impossible for the reviewers to check. During the review process some wrong data and a few calculation mistakes were identified and corrected, some of them had a considerable influence on the results and conclusions. The Panel cannot make a guarantee that other data- and calculation errors will not be found.

Electricity scenario
Despite the separate report on energy and transport scenarios, there is still not a sufficiently lucid explanation of:

- What the "long term base load marginal" actually means or is in practice
- Why this scenario has been chosen in preference to others, which are more conventional, and which would thus, to many, be more logical.

It can only be re-iterated that the use of a non-standard scenario constitutes a weakness of the study, although it follows a recent recommendation from an expert panel formed during the study and other recent international recommendations but without much practical experiences.

The choice of electricity generation scenario critically affects the study, notably that the use of the marginal scenario can, and does, give appreciably different results to those obtained with more conventional/accepted scenarios, and therefore introduces a bias into the comparisons which may render their validity questionable.

It is particularly difficult to understand why a future electricity generation scenario (*i.e.* the marginal) has been used as basic scenario for the study, which itself is a "snapshot in time", of the systems in the past (*i.e.* 1993-96). Thus, the study data temporality is clearly not compatible with the electricity generation data temporality since the latter pertains to a future/predicted situation. In this context, it is worth noting that the "Average EU data" used for electricity generation in the sensitivity analyses is for 1994, corresponds well with the process and emissions data on the systems studied.

The sensitivity analysis points to the electricity generation scenario as being very important, if not dominant. Data are presented showing the effect of changes in the individual systems. Some conclusions should have been made regarding the ranking between systems, when other energy scenarios are used for the calculations, *e.g.* will aluminium cans be better in some impact categories, if other system boundaries are applied?

Impact assessment

Impact assessment was conducted according to the Danish EDIP method. The appropriateness of the method for this application, and the strong and weak points in this method should have been explained more thoroughly.

For many of the systems potential toxicity and ecotoxicity are pointed out as among the most important impact categories. This may be true, if only the naked figures are used, but a discussion about the precision of the assessment and the environmental relevance of these parameters is missing in general. In the EDIP-reports it is stated that the assessment should be taken only as an order of magnitude of the impact. Therefore, emphasis should not be put on these categories unless a discussion of the precision is included. It is recognised that the authors in many cases indicate this, when comparing the systems, but in the assessment of the single systems, a more detailed discussion is required.

Comparison with previous study
The inclusion of a comparison and discussion of the present study with the previous one is excellent and, again, fulfils a methodological need and demonstrates thoroughness. In this respect, the summary table on page 4 of the "Comparisons" report is exemplary since it not only shows the differences between the studies but quantifies them. Again, the comparisons become very detailed in the report itself. Illustrations with bar diagrams would help to make the report more comprehensible. Some indication of the significance of the differences is needed. The direct comparisons are weakened by the fact that the scope, boundaries, scenarios and inventory items of the previous and present study are rather different.

H.4 Overall conclusion

Overall, the methodology applied appears to be sound, transparent and correspond to recognised standards or practice (ISO, SETAC etc.). Attention has been correctly directed to the known issues - such as data, assumptions, recycling etc. - and, in general, the treatments of these are certainly adequate. However, a more convincing justification for the energy scenario choice could have been presented.

The study is in general very well executed, presented and reported. Although in total very voluminous, it is properly laid out in the format of a summary report; a main report; detailed individual reports for each system studied; and appendices of detailed data. Commendably included as appendices are those on energy generation/transport; the critical review and subsequent discussions; and the comparison with the previous study. This endorses the thoroughness of the study and demonstrates that the requirements of the ISO standard on reporting appear to have been addressed and fulfilled.

Reporting of the conclusions of the study could be made in more condensed and easy understandable way for a decision support. In its present form this study report is not quite suitable as support of public decision making, and it cannot be the solely background for predicting, which of the packaging systems are most environmentally preferable. For such an evaluation many other aspects, either omitted in the study (*e.g.* littering, migration from packaging materials, retailer processes, work environment, functionality, hygiene, home transport, economics) or not adequate serviced by the LCA tool (*e.g.* local environmental impacts), also have to be taken into account.

Furthermore, the significance of the results and the representativity of the data should be worked out more clearly. Presenting the results in a condensed manner, *e.g.* by ranking the systems in different scenarios, must be considered as necessary in order to gain a better overview of the very detailed assessments.

H.5 Literature

ISO 14040:1997
Environmental management - life cycle assessment - Principles and framework (7. Critical review).

SETAC 1993:
Consoli F, Allen D, Boustead I, de Oude N, Fava J, Franklin W, Jensen AA, Quay B, Parrish R, Perriman R, **Postlethwaite D**, Séguin J, Vigon B, eds. Guidelines for Life-Cycle Assessment: A "Code of Practise". From the workshop held at Sesimbra, Portugal, 31 March - 3 April 1993.

Annex I:

Response to critical review

This annex includes the response of the project team to the final report of the critical review panel. The headings in this annex refer to the various sections in Annex H.

The project group acknowledges the difficulties encountered by the critical review panel when reviewing this large study in a short period of time. We also gratefully acknowledge the points of commendation made by the panel.

Part of the criticism brought up by the reviewers is not specifically directed towards this particular study but towards LCA as such. We agree that there is a need for further development in the LCA methodology. We also consider the development of reporting techniques to be an important task for the LCA community. However, this task is outside the scope of this project.

Section H.2 General comments

Communication, line 8-11:
In the final report, section 15.1 has been expanded to include a summary of all main conclusions.

Significance of the results, line 7ff:
We believe that our interpretation phase (assessment of data quality and data gaps, and sensitivity analyses) provide a much more solid basis for assessing the significance of the differences than simple 10% or 20% rules. Our interpretation results indicate a difference of 20% can be significant when fairly similar systems are compared, such as the steel and aluminium can systems. However, when the systems compared are very different - such as the refillable PET-bottle system and the aluminium can system - much larger differences are needed to be significant (see chapter 13).

In the final report, rank orders are presented when possible (see, *e.g.*, section 15.1).

Representativity:
Representativity is dealt with in the data quality assessment (see section 5.4.2 in Technical Reports 1-6): the representativity of the most important processes are described qualitatively in a table and in the text. Admittedly, these descriptions could have been elaborated. In response to the critical review, they have been slightly improved.

Section H.3 Specific comments

Electricity scenarios, par.4:
It is correct that there is a discrepancy between the study data temporality and the choice of marginal technology. This discrepancy follows from the practical difficulties in obtaining data on future processes. As indicated in section 2.9.2, par.1, we are aware of this discrepancy. We identified data on future processes to be ideal with respect to the purpose of this study. However, since the uncertainties involved in estimating such data are high, we decided to use as recent data as possible instead.

We also identified marginal data to be ideal for markets where a decision on Danish beverage packagings have a marginal effect. For these parts of the systems, we used marginal data when possible. We were not able to obtain marginal data for all relevant processes, but we believe we used marginal data where it was most important, *e.g.* for electricity production, waste management and steel recycling.

In other words, our view of what are the ideal data is consistent, but for practical reasons it was not possible (within the framework of this study) to obtain what we considered to be the ideal data for all processes. This fact was taken into account in the interpretation phase (see section 5.4.1 in Technical Reports 1-6).

Electricity scenarios, par.5:
Our electricity scenarios represent the best estimates we can make today regarding what is the marginal electricity production. However, the uncertainties are large. These uncertainties are taken into account in the conclusions concerning the ranking of the systems. The significance of the differences between the systems are assessed based on the interpretation results and, as the reviewers state, the interpretation identifies the uncertainty regarding the electricity generation as very important. The sensitivity analyses and the conclusions take the broad span of electricity data into account. In all relevant parts, the average EU data are within this span.

Impact assessment, par.2, line 2:
Toxicity impacts and ecotoxicity impacts are not pointed out as among the most important impact categories. In the dominance analyses (section 5.1 in Technical Reports 1-6) they are identified as the categories to which the systems contribute the most, but the importance of the categories is deliberately not discussed. However, in response to the reviewers comments, the precision of the dominance analysis are discussed in the final versions of the reports.

In response to the critical review, the toxicity results are removed from the final version of the main report, since no significant differences in toxicity impacts were observed between the systems. The toxicity results are only included in the technical reports.

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Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks

Undertitel:
Main Report

Forfatter(e):
Ekvall, Thomas; Frees, Niels; Nielsen, Per H.; Person, Lisa; Ryberg, Anna;
Weidema, Bo Pedersen; Wesnæs, Marianne Suhr; Widheden, Johan

Udførende institution(er):
Miljøstyrelsen. Rådet vedr. genanvendelse og mindre forurenende teknologi (spons);
Chalmers Industriteknik; Instituttet for Produktudvikling

Resumé:
Rapporten indeholder en livscyklusvurdering, hvor potentielle miljøeffekter fra forskellige eksisterende og alternative emballagesystemer til øl og læskedrikke, påfyldt og solgt i Danmark, sammenlignes. Miljøvurderingen sammenligner retur- og engangsflasker af hhv. glas og PET samt aluminiums- og ståldåser.

Emneord:
livscyklusvurdering; emballage; drikkevarer; øl; genanvendelse; aluminium; stål; systemanalyser; scenarier; retursystemer; transport; metodik; UMIP; polyetylentereptalater

Andre oplysninger:
Hertil hører 7 bilagsrapporter:
Refillable Glass Bottles (Miljøprojekt, 400), Disposable Glass Bottles (Miljøprojekt, 401),
Aluminium Cans (Miljøprojekt, 402), Steel Cans (Miljøprojekt, 403),
Refillable PET Bottles (Miljøprojekt, 404), Disposable PET Bottles (Miljøprojekt, 405),
Energy and Transport Scenarios (Miljøprojekt, 406).
Opdatering af Miljømæssig kortlægning af emballager til øl og læskedrikke
(Arbejdsrapport fra Miljøstyrelsen, 62/1995 og 70 - 76/1995) og af
Miljøvurdering af emballager til øl og læskedrikke (Arbejdsrapport fra Miljøstyrelsen, 21/1996)

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Main Report

Author(s):
Ekvall, Thomas; Frees, Niels; Nielsen, Per H.; Person, Lisa; Ryberg, Anna;
Weidema, Bo Pedersen; Wesnæs, Marianne Suhr; Widheden, Johan

Performing organization(s):
Stiftelsen Chalmers Industriteknik, Chalmers Teknikpark, S-412 88 Göteborg;
Institute for Product Development, Technical University of Denmark, DK-2800 Lyngby

Abstract:
This report contains a life cycle assessment (LCA) comparing the potential environmental impacts associated with different existing or alternative packaging systems for beer and carbonated soft drinks that are filled and sold in Denmark. The study compares refillable and disposable glass and PET bottles and steel and aluminium cans. The study is an update of a previous study carried out in 1992-1996.

Terms:
life cycle assessment; packaging systems; beer; soft drinks; recycling; aluminium cans;
steel cans; PET bottles; glass bottles; EDIP method

Supplementary notes:
The project comprises the main report and 7 supplementary reports: Refillable Glass Bottles (Environmental Project, 400), Disposable Glass Bottles (Environmental Project, 401), Aluminium Cans (Environmental Project, 402), Steel Cans (Environmental Project, 403), Refillable PET Bottles (Miljøprojekt, 404), Disposable PET Bottles (Miljøprojekt, 405), Energy and Transport Scenarios (Miljøprojekt, 406).
The previous reports were published in Danish: Miljømæssig kortlægning af emballager til øl og læskedrikke (Arbejdsrapport fra Miljøstyrelsen, 62/1995 and 70 - 76/1995), and Miljøvurdering af emballager til øl og læskedrikke (Arbejdsrapport fra Miljøstyrelsen, 21/1996)

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Miljøprojekt (Environmental Project)

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Nr. 369: Environmental Assessment of Textiles
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Nr. 399: Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks : Main Report
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Nr. 405: Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks : Disposable PET Bottles
Nr. 406: Life Cycle Assessment of Packaging Systems for Beer and Soft Drinks : Energy and Transport Scenarios

This report contains a life cycle assessment (LCA) comparing the potential environmental impacts associated with different existing or alternative packaging systems for beer and carbonated soft drinks that are filled and sold in Denmark. The study compares refillable and disposable glass and PET bottles and steel and aluminium cans. The study is an update of a previous study carried out in 1992-1996.

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