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Reuse and Recycling - Role of Life Cycle Assessment (LCA) to inform decision-making

A review of LCA studies commissioned by EUROPEN

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Summary conclusions

General

- Life Cycle Assessment (LCA) is a decision support tool that facilitates the comparison of alternative products and services that perform the same function (eg alternative packaging systems) from an environmental perspective;
- An LCA typically quantifies the use of raw materials and energy and releases to air, water and land as well as assesses the associated impacts towards environmental concerns such as global warming and depletion of non-renewable resources from all steps from extraction of raw materials, through manufacture and conversion, distribution, use and disposal;
- The results of an LCA can be used to determine the trade off's between alternative systems (eg shift from one pack type to another or, in the context of this study, comparisons of reuse versus recycling);
- LCA methodology has evolved much since the first studies were carried out more than thirty years ago;
- In 1997, ISO published the first of a series of international standards that have helped to capture 'best practice' as well as introduce consistency with regard to how studies are undertaken and reported;
- When using the results of an LCA to make a public declaration relating to a comparison of alternative products and services, ISO demands that a critical review is undertaken by independent experts able to comment, guide and advise on issues relating to the robustness of the methodology employed, data quality as well as whether the data and calculated results have been interpreted correctly;
- As with any complex methodological procedures, the publication of the ISO standards does not mean to say that all aspects of every LCA will be carried out in precisely the same way;

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In his capacity as an expert on Life Cycle Assessment, Neil helped to write the ISO standards on Life Cycle Assessment and has contributed to methodological guidance notes on LCA used by Government Bodies (eg the Environment Agency of England and Wales) and industry (eg American Forest & Paper Association).

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- Sensitivity analysis can be used to test assumptions and methodological decisions made with the key consideration ultimately being the robustness of the conclusions made.

Reuse and recycling – scope of study

- This review considered a number of LCA studies (refer to Annex A) that concern reuse and recycling;
- The purpose of the review was to make an independent determination of how well the studies had been carried out – with a particular focus on whether the conclusions made relating to the relative merits of reuse compared to recycling were technically sound and justifiable;
- For clarification, the primary purpose of the review was *not* to provide guidance or a commentary on how LCA might be used to support policy and regulation. However, the findings of this research may be used to inform discussions concerning the use of LCA as a tool to make improvements under free market conditions as well as how targets set for reuse and recycling are defined within policy and regulation;
- The study concentrated on the use of LCA methodology and the way in which the findings were interpreted;
- The study did not consider factors such as the use of financial instruments (eg deposits) or wider sustainability issues such as social and economic analyses;
- The number and final list of studies reviewed were agreed with EUROPEN on the basis of their perceived relevance to informing the debate on the relative merits of reuse versus recycling;
- Studies were not included or excluded on the basis of any prejudice that might be introduced regarding their influence on the findings of this review;
- The observations and conclusions provided in this report are entirely those of the author with EUROPEN emphasising throughout the importance of the independence of the author when compiling this report;

Reuse and recycling – summary conclusions

The findings of this research suggests that the environmental benefits of reuse and recycling – or, more specifically, in the context of this study, multi and single trip packaging – are indistinguishable. In other words, whilst some studies show that reuse is preferable to recycling and others show the opposite, the reality is it is not possible to make a blanket conclusion owing to the need to take into account many factors that affect the outcomes of comparisons made.

The author – and EUROPEN as evidenced from its publications – emphasise the importance of Life Cycle Assessment (LCA) as a decision support tool. Many organisations, including EUROPEN members, use LCA and life cycle techniques to improve pack designs and the efficiency of packaging systems. Indeed, the majority of the first LCAs conducted were all directed at evaluating and improving pack designs and packaging systems.

Further conclusions were:

- The review of the studies did not reveal a single answer to the question of whether reuse or recycling are 'environmentally preferable';
- Respecting that the dates of publication of those articles reviewed spanned the period 1993 to 2003, there was a wide variation in methodology employed when compiling the LCA results reported;
- Transparency of reporting varied markedly as did key issues such as how, or indeed whether, sensitivity analysis was used to test the robustness of the conclusions made;
- Factors that affect the outcomes of environmental preference between reusable and recyclable packaging include:
    - Pack types investigated (material, volume, weight) and packaged products considered;
    - Recovery and recycling rates assumed;

  - Assumptions regarding handling and treatment of waste arisings occurring during recovery and recycling;
  - Fuel mix used (and assumptions regarding how that mix might change over time);
  - Transport distances assumed;
  - National versus international coverage;
  - The inclusion of secondary packaging as part of the 'packaging system' and assumptions regarding whether or how secondary packaging was reused/recycled;
  - Data quality (in particular with regard to age and specificity/coverage);
  - Consumer behaviour and the importance of achieving high participation rates in reuse and recycling schemes;
- The reporting of those studies reviewed was generally poor albeit in fairness, not all the studies reviewed were intended to provide a detailed and fully transparent account of the work reported;
- Where reported, sensitivity analysis revealed the influence of a number of parameters such as collection rates, energy mix to generate electricity, transport distances, etc on the relative environmental merits of reuse and recycling;
- Critical review – in the very limited instances where this was included as part of the scope of LCA work reported – provided a valuable contribution to assurance, with independent experts offering opinions on what had been carried out well, where elements of the work undertaken were arguably weak and what aspects of the study might be improved.

Background

EUROPEN (www.europen.be), the European Organisation for Packaging and the Environment, is an independent trade association that represents the interests of packaging producers as well as fillers, retailers and consumers concerning issues related to packaging and the environment.

EUROPEN has contributed much to the debate concerning the most efficient way to deliver goods and services as well as how to deal with used packaging once it has served its primary function and is designated as 'waste'.

It produces a number of publications including, for instance, '*European and National Legislation on Packaging and the Environment*' (April 2004), that aims to assist those in the packaging chain to ensure compliance with the various laws across Europe.

The EC Directive on Packaging and Packaging Waste (94/62/EC) is a key instrument that sets targets for recovery and recycling. EUROPEN has publicly welcomed the revision to the EC Packaging and Packaging Waste Directive (December 2003) that sets the increases in recovery and recycling targets (25% to 55% and 50% to 60%, respectively) effective from the end of 2008 except Ireland, Greece and Portugal where the deadline is 2011. It has also voiced its concerns about the ability of the Accession States to meet these targets by 2012 to 2015. EUROPEN has also welcomed the clarification that incineration with energy recovery will count towards recovery targets.

One issue that EUROPEN wishes to seek guidance on is whether there is a scientific argument that differentiates reuse and recycling of packaging from an environmental perspective. Of particular concern to EUROPEN and its members is the introduction of mandatory deposits in Germany for all non-refillable containers for beer, water and carbonated soft drinks.

This research is aimed at helping EUROPEN and its members understand whether independent research conducted by a number of practitioners across Europe provides a

scientific basis for differentiating between multi and single trip packaging from an environmental perspective.

Scope

This research has examined a number of articles and papers (Annex A) that are central to informing the debate on the relative environmental merits of reuse and recycling. Ultimately, the goal of this work has been to determine, based on the findings of those articles and papers reviewed, whether reuse is environmentally preferable to recycling, or *vice versa*, or indeed whether the relative merits of reuse and recycling from an environmental perspective are insufficiently distinguishable.

Significantly, this research does not concern whether or not there is an argument or justification for the introduction of mandatory deposits. Its focus is limited to the environmental merits of reuse and recycling only as reflected in the outcomes of those articles and papers reviewed.

Methodology

Selection of documents for inclusion within the scope of this study

It is essential to point out that every effort has been made to avoid the introduction of any prejudice that might influence the findings and recommendations of this research.

As in all studies of this nature, it has not been possible to review every article and paper published related to this topic and hence the findings presented are based on the outcomes and conclusions of those studies reviewed only.

As indicated above, this study has involved a review and analysis of articles and papers that are central to informing the debate on the relative environmental merits of reuse and recycling. Out of over fifty titles of articles and papers initially identified, the author provided an assessment of their perceived relevance to the scope of this study (expressed as high, medium or low) based on his expert knowledge of the subject.

After this initial screening, EUROPEN then selected those studies for inclusion within the scope of this research. All of the articles and papers reviewed fell into the 'high perceived relevance' category and were chosen on the basis of their technical scope (pack types, recovery and recycling technologies, geographical scope and perceived data quality), reputation of the authors and prominence as reference literature used to inform this topic.

The final list of articles and papers reviewed are referenced in Annex A.

Comparison of reuse versus recycling

Life Cycle Assessment (LCA) is a methodology used to inform decision making on the basis of a wealth of information generated concerning the environmental performance of products and services.

For summary information on LCA methodology, its use and applications refer to Annex B and also the publications section of EUROPEN's web (http://www.europen.be/whats/whats_europen.shtm).

Whilst the initial intention was to select studies that shared in common best practice Life Cycle Assessment (LCA) methodology, it should be noted that the methodologies employed in the articles and papers reviewed ranged from full LCA studies to methodologies adapted from a life cycle approach.

For example, Ecobilan (1995) reported on the determination of equivalent mass of waste associated with multi trip versus single trip containers based on assumptions of the number of trips and waste arisings across the life cycle / delivery system and GUA (2000) reported on

the determination of the financial and economic implications (production costs, macro-economic effects linked to employment and value creation and external costs linked to changes arising as a consequence of environmental impacts) using a life cycle approach to model alternative packaging waste management scenarios.

Discussion of findings

The articles and papers reviewed were published over the ten year period 1993 – 2003. They vary widely with regard to pack types considered, recovery and recycling technologies, geographical scope and data quality. They also vary with regard to detailed aspects of methodology.

The main areas where the studies differ concern:

- Data quality – eg age and source of data;
- Geographical scope – eg country specific;
- Systems boundary setting (ie what has or has not been included within the scope of the study) – eg whether or not secondary packaging is included;
- Assumptions regarding reuse and recycling rates;
- Assumptions regarding transport distances;
- Assumptions concerning national energy mixes (ie how electricity is generated via the national grid);
- Data handling techniques, in particular with regard to:
    - The conversion of life cycle inventory data (ie use of raw materials and energy and releases to air, water and land) into measures of potential environmental impact;
    - The use of sensitivity analysis to determine the robustness of conclusions drawn;
- The transparency of reporting;
- The use or otherwise of an independent Critical Review panel to provide greater assurance regarding the quality of the work undertaken, the conclusions draw and how the work has been reported.

Respecting that the first ISO standard on LCA was not published until 1997 (ISO 14040: Environmental Management - Life Cycle Assessment: Principles and Framework), it is inevitable that the studies vary enormously in their ability to comply with the requirements of the ISO standards on LCA. In fairness also, the articles and papers reviewed also varied with regard to their intended purpose and audience, with a number of the documents being summary documents only.

Interestingly, none of the studies reviewed could claim to fulfil every recommendation made in the CEN Report on 'Criteria and methodologies for life cycle analysis of packaging' (published in 1999). The latter provides a number of examples that illustrate aspect of LCA methodology for packaging and packaging systems. This having been said, a number of the recommendations made in the CEN Report are dependent on the scope of the study conducted and hence may not be relevant for every packaging related study.

What does emerge from this research though is a very strong message that there is not a 'single size' fits all answer to the question of whether reuse is environmentally preferable to recycling with each study revealing factors that influence the outcomes observed. This observation on based on a comparison of the findings of the different studies reviewed as well as on the results of sensitivity analysis where reported within individual studies to investigate the effects of data variation.

For instance, some of the studies highlighted the importance of transport and distribution as a key factor that affects the choice of packaging and outcomes of determinations of the relative environmental preference between multi and single trip packaging. In general, the longer the transport distance, the more the results favour the use of lighter weight, recyclable packaging,

albeit this depends on the infrastructure in place to collect, sort and re-process those packaging materials recovered (Bischoff, 1993, Prognos 2002).

Other studies highlight the importance of assumptions concerning detailed elements of recovery and recycling, for example, the sensitivity of the results to a high assumed recovery rate for glass or the fate / handling of aluminium when recycling two piece cans made of both steel and aluminium (Chalmers, 1998).

Interestingly, none of the studies reviewed stands out as a 'land mark' model that might be used as the basis for setting a strategy for dealing with Packaging and Packaging Waste across the European Union. In part this observation is based on the methodology employed, the data used and the findings presented. It is also made on the basis of the transparency of reporting that in turns influences the degree of confidence associated with the work undertaken.

For a more detailed account of the articles and papers reviewed, together with an assessment of their strengths, weaknesses and robustness of conclusions made, refer to Annex A.

Annex A Summary of studies reviewed (Table 1 of 3)

	1	2	3
Title	Abschaetzung der oekonomischen and oekologischen Effekte der Einfuehrung einer Pfandpflicht auf bestimmte Getraenkeverpackungen	Mandatory deposit on one ways drinks packaging: Ecologically negligible efficiency and economic waste of resources (non official translation)	Volswirtschaftlicher Vergleich von Einweg und Mehrwegsystemen
Author	Prognos	Prognos	GUA
Year	2003	2002	2000
Nature of document	Report	Summary Paper	Final Report
Number of pages	109	3	8
Commissioning Body	Umweltbundesamt (UBA)	Umweltbundesamt (UBA) (Original work that this paper summarises)	Federal Ministry for Agriculture, Forestry, Environment and Water, Federal Ministry of Economics and Employment and Austrian Association of Beverage Producers
Transparency of reporting	Poor – in particular with regard to systems boundaries, assumptions made, transport distance and sources of data	Not possible in such a short paper. Paper focuses mainly on conclusions of 'Phase II of the UBA LCA project for drinks packaging undertaken by Prognos and Ifeu/UBA)	Not very transparent – owing to level of detail possible in such a short report.
Could work be reproduced/replicated from report?	No	No	No
Compliance with ISO 14040 standards on LCA	Reporting - No; Methodology – Unclear.	[Of study that this paper summarises] - Not mentioned or claimed in this summary paper	Not clear. Whilst this study claims to concern economic and ecological effects, the latter are expressed as external costs (ie those costs to ameliorate environmental impacts not internalised, eg within retail price). It is not possible to determine

			whether the environmental data on which the external costs were derived were obtained using a life cycle approach.
Country/-ies	Germany	Germany	Austria
Functional Unit	Per 1000 litres of beverage	Per 1000 litres of beverage	Varies (based on volume of container)
Pack types / volumes	Beer, non-alcoholic beverages and water. metal, glass and plastic	Cans, cartons, PE, PET, glass mentioned specifically.	Beer (glass, cans - 0.5 l), milk (cartons, 1 l, Polycarbonate, 1 l), non-alcoholic beverages (PET, 1.5 l) and water (glass, 1 l and PET, 1.5 l)
Data	Public domain sources (previous Umweltbundesamt study) dating back to mid 1990s as well as market research for consumption of beverages	Data sources not stated specifically. Reference made to the Phase II UBA LCA being public domain.	Reference made to GUA and IFIP, 2000.
Waste management options	Reuse, recycling	Reuse, recycling	Reuse, recycling
Reuse/Return rate	75%, 80%, 90%	Not stated specifically	Not stated specifically.
Recycling	Not clear.	Not stated specifically	Not stated specifically.
Incineration with energy recovery	Not modelled.	Not modelled	Not modelled.
Allocation	Not clear.	Not stated	Not clear.
Transportation / distribution	Transport distance has a significant bearing on the findings (eg with regard to choice of one way versus multi trip packaging)	Whilst transport distances are not stated specifically, The summary report does indicate that transport distance has a significant bearing on the findings (eg with regard to choice of one way versus multi trip packaging)	Not mentioned in this report.
Secondary packaging included?	Unclear. Not stated specifically	Unclear. Not stated specifically	Not mentioned in this report.
Sensitivity analysis	Yes. Based on market share of one way versus multi trip and transport distances	Not stated.	Considered changes in market share of pack types considered.

	between production and consumer.		
Impact assessment	Global warming potential, resource consumption (crude oil equivalents), air acidification potential, photochemical smog formation, eutrophication, land use and landfill volume.	'Ecological / environmental impacts' mentioned many times. Unclear what this refers to precisely.	No.
Financial / economic considerations	The paper comments on the costs of implementing and administering the deposits scheme – as well as the implications of this for the DSD recovery system and producers/packers/fillers. The report also considers the implications for the waste management sector, the retail sector, the costs associated with tackling the litter problem as well as changing consumption patterns associated with one way versus multi trip packs.	The paper comments on the costs of implementing and administering the deposits scheme – as well as the implications of this for the DSD recovery system.	Study considers production costs, macro-economic effects (employment and value creation) and ecological effects measured as externalities.
Social impacts	Consider direct and indirect effects on employment. Direct = those sectors identified above; indirect = the German economy generally.	No.	Indirectly via economic considerations assessed.
Overall assessment of quality	Fair albeit the methodology is questionable regarding the ability to generate robust and statistically proven analysis and conclusions (eg owing to the limited time frames considered and small data sets for each time frame).	Poor.	Fair albeit study is not reported in a transparent manner.
General comments	Study considers three times frames 2002 – situation without deposits, 2003 – situation following introduction of German Packaging Ordinance and 2004 – situation taking into account proposed changes to the Packaging Ordnance in Germany.	Whilst the life cycle inventories were compiled by Prognos and Ifeu, the evaluation as well as the conclusions and recommendations were performed by UBA. The authors conclude that the	This is largely a 'cost benefit analysis' study and not an LCA study. The authors conclude that one way packaging appears favourable for all products and scenarios

	The authors conclude that the introduction of deposits on one-way packaging leads to a marginal reduction in environmental impacts only.	introduction of a mandatory deposit on one-way packaging will not lead to significant reduction in environmental impacts. Key factors affecting choice of packaging are volume of container and transport distance for distribution.	considered. It is not abundantly clear how these conclusions were derived.

Annex A Summary of studies reviewed (Table 2 of 3)

	4	5	6
Title	Macro-Economic Comparisons of One-Way and Multi-Way Systems	Report on criteria and methodologies for life cycle analysis of packaging	Life Cycle Assessment of Packaging Systems For Beer and Soft Drinks – Main Report No. 399
Author	GUA	CEN	Chalmers Industriteknik
Year	2000	1999	1998
Nature of document	PowerPoint presentation	Report	Report
Number of pages	22 slides	17	385
Commissioning Body		European Committee for Standardisation	Danish Environmental Protection Agency
Transparency of reporting	An introductory paper that summarises a study that investigated the macro-economic effects of single trip versus multi trip beverage packaging in Austria. The presentation introduces Welfare Cost Benefit Analysis as an extension of LCA methodology. Using an externalities methodology, the authors derive monetary values for multi trip versus single trip packaging systems (based on the whole life cycle) as well as place a monetary value on the 'ecological benefits' that arise.	A well written technical report on LCA methodology, to be read in conjunction with the ISO 14040 series standards on LCA. Provides detailed recommendations on all aspects of LCA methodology specifically for packaging and packaging systems. ***It should be noted that none of the other studies reviewed could claim to fulfil every recommendation made in this report.***	An extremely comprehensive and generally well reported study. It should be noted that this review considered the Main Report only and did not examine those reports issued for specific systems 'summarised'.
Could work be reproduced/replicated from report?	No.	Not appropriate (N/A).	It is likely – especially by reference to the full suite of reports – that most of the systems considered in this study could be re-created with a fair degree of accuracy. By contrast, it is anticipated that for a number of linked

			data sets (eg electricity production, landfill modelling, transportation models, impact assessment parameters), data gaps would be identified when seeking to re-create the inventories compiled.
Compliance with ISO 14040 standards on LCA	Not clear.	N/A.	Yes.
Country (countries)	Austria.	N/A.	Denmark
Functional Unit	Varies (based on volume of container).	N/A.	Per 1000 litres of beverage
Pack types / volumes	Aluminium and tin cans (0.5 l); cartons (1.0 l); Polycarbonate (1.0 l) PET (1.5 l) and glass (0.5 l, 1.0 l).	N/A.	Aluminium and steel cans (with aluminium lids), glass bottles, PET bottles. Volumes considered ranged from 33 cl, 50 cl to 150 cl.
Data	Not clear. Financial data drawn from GUA's own database.	N/A.	Source of data used varied – site specific data were used for glass production; European average data used for production of primary steel, aluminium and PET. Detailed accounts of data quality are considered in the Technical Reports issued along side this Main Report.
Waste management options	Reuse, recycling, incineration and landfill shown on systems boundaries flow diagram. Not clear though how waste management scenarios for single trip packaging was modelled.	N/A.	Reuse, recycling, incineration with energy recovery, landfilling.
Reuse/Return rate	Not stated specifically. Slides show increases in market share of one way and 'reference' packaging, together with pack types substituted.	N/A.	For refillable bottles, 98.5% was assumed to be collected.

Recycling	Not stated specifically.	N/A.	For cans and disposable bottles, 90% was assumed to be collected.
Incineration with energy recovery	Not stated specifically.	N/A.	For each MJ of waste (lower heating value), 0.768 MJ of heat and 0.039 MJ of electricity were assumed to be produced. Recovered energy was assumed to replace the same amount of heat and electricity produced in other ways (eg heat from household boilers and electricity from the long term marginal electricity supply).
Allocation	Not stated specifically.	N/A.	In line with ISO requirements where a hierarchy of methods is proposed, starting off with avoiding allocation by systems boundary expansion, then allocation by 'physical causality' – eg mass, then on the basis of economic or some other relationship.
Transportation / distribution	Not stated specifically.	N/A.	Environmental impacts associated with transport included. Different truck types assumed depending on where they are used in the 'life cycle'. Transport includes distribution of the beverage from filler (eg brewery) to retailer and return of empty packaging.
Secondary packaging included?	Not stated specifically. Not shown on summary systems boundary flow diagram	N/A.	Production and waste management of secondary and transport packaging included. 'Conversion activities' such as moulding and folding excluded.
Sensitivity analysis	Not stated specifically.	N/A.	Reported for each of the packaging comparisons made. A comprehensive sets of parameters were subject to sensitivity analysis,

			including recycling rates and technologies, weight of packaging, allocation methods, electricity production, transport data, end of life of secondary packaging.
Impact assessment	Not stated specifically. Reference is made to inventory flows (eg carbon dioxide, 'resources' and 'waste') and 'ecological effects'.	N/A.	Comprehensive and in line with ISO requirements. Includes global warming potentials, stratospheric ozone depletion, photochemical ozone formation (smog), air acidification, nutrient enrichment (eutrophication), human toxicological and ecotoxicological impacts, waste flows and resource depletion.
Financial / economic considerations	Welfare cost benefit analysis considers internal effects ('business effects and substituted business effects) and external effects (incidental emissions, saved/avoided emissions and risk surcharge for landfill)	N/A.	No.
Social impacts	Presentation states that the methodology includes an 'analysis of effects on employment and value added'.	N/A.	No.
Overall assessment of quality	Not possible to determine.	N/A.	Excellent albeit the study is weakened and indeed criticised by an external Critical Review Panel for its use of an assumed future marginal electricity production model.
General comments	The presentation concludes that the 'ecologically aware consumer' should buy mineral water in glass multi trip bottles since this results in	This report contains a number of useful examples to illustrate methodological considerations. It also offers guidance on issues	By far the most comprehensive and well reported study reviewed. A return scheme is assumed to operate for all reuse and recycling activities.

	lower emissions (eg carbon dioxide), uses less resources and gives rise to lower waste arisings. It also concludes that '*In no way does this study evaluate these beneficial effects any lower than do other recent eco-balances'*. Respecting that this is a poor translation into English, it is assumed this means that the authors are seeking to compare the results of this work with other environmental comparisons and draw a parallel in the findings made.	related to the use and interpretation of the results of an LCA. Interestingly, none of the studies reviewed in this work that were carried out after this report was published make reference to it.	Landfilling of production waste and ash/slags from incineration excluded. The authors include summary tables that seek to summarise the wealth of information generated in the form of ranking. This does not produce clear cut differences since results obtained overlap. As a very crude conclusion though, multi trip glass and PET bottles and single trip aluminium cans demonstrate lower impacts albeit the authors emphasise that some of the differences between the systems investigated are very small, the uncertainties sometimes large and the results can be quite sensitive to the assumptions made.

Annex A Summary of studies reviewed (Table 3 of 3)

	7	8	9
Title	Equivalence between refillable and recoverable drinks packaging in Belgium (English translation)	Einweg und/oder Mehreg? – Stellungnahme zur Problematik One way and/or multi way packaging? Statement on the issues (English translation of article in PETCORE)	One-way Containers Returnable Containers A study of the German Packaging Regulation Effects and Counterarguments Volume I
Author	Ecobilan	Prof Dr Paul Finck	Dr Ing Ernst Bischoff SA
Year	1995	1994	1993
Nature of document	Report	Paper	Report
Number of pages	95	14	136
Commissioning Body	FOST PLUS	PETCORE	Multi-client study
Transparency of reporting	Fair/Poor	N/A. This is an article that discusses methodological issues associated with comparing reuse and alternative waste management scenarios as well as provides comments on some work undertaken in Germany concerning a comparison of milk and beer packaging systems.	Poor. General information provided only on systems/processes included. Detailed aspects of methodology (eg allocation methods, handling of open and closed loop recycling, transportation and waste models, etc) are not included.
Could work be reproduced/replicated from report?	No	N/A	No.
Compliance with ISO 14040 standards on LCA	No	N/A	No.
Country (countries)	Belgium	N/A – albeit the article refers to work undertaken in and specific to Germany.	Germany
Functional Unit	Results are expressed in mass of waste per litre of drink sold in refillable packaging on the Belgian market.	N/A	1000 units of packaging
Pack types / volumes	Glass (25 cl and 75 cl)	N/A	Bottles: glass (33 cl, 1 l), PET (33 cl,

	Aluminium, Steel (20 cl and 33 cl) PET and PVC (1.5 l) Cartons and PE (1 l)		1.5 l), PVC (33 cl, 1.5 l); Cans: aluminium (33 cl), tinplate-aluminium (33 cl) and tinplate (33 cl); Jar: Glass with tinplate twist off cap (1 l); Cartons: cartonboard with aluminium barrier layer, (25 cl, 1 l); Pouch: PET-aluminium composite film (20 cl).
Data	Statistical data were taken from market research conducted by FOST PLUS. Whilst it is not clearly stated, it is assumed 'environmental data linked to mass' comes from Ecobilan's proprietary life cycle database.	N/A	Sources of data (mainly public domain) stated – spanning period 1983 to 1991.
Waste management options	Reuse, recycling, incineration	Various.	Reuse, recycling
Reuse/Return rate	Various to allow levels of equivalence to be determined.	N/A.	Variety of rates examined. Results presented for return rates of 90% and 95%
Recycling	Various to allow levels of equivalence to be determined.	N/A.	Specific levels of recycling stated throughout for results presented (eg 20 to 100 % for glass recycling)
Incineration with energy recovery	An assumption is made regarding waste levels associated with the incineration of PVC packaging (associated with the treatment of fumes). Other materials are assumed to generate 'negligible mineral residue after incineration'.	N/A.	Some results shown for different rates of incineration both with and without enegy recovery (eg 31% to 80%)
Allocation	Not stated specifically.	N/A.	Not specifically stated.
Transportation / distribution	N/A since transport and distribution	N/A.	Transport distance examined as a key

	are not assumed to generate waste *per se*.		factor affecting the choice of packaging (both with regard to material type and reusable versus recyclable).
Secondary packaging included?	No.	N/A.	Included with assumptions made regarding 'standard' secondary packaging used throughout.
Sensitivity analysis	No.	N/A.	Not directly albeit results are presented for a wide range of variables, showing ranges for different systems compared (ie different reuse, recycle and incineration rates for different pack types compared all on the same axes.
Impact assessment	No.	N/A.	In addition to parameters such as energy consumption and landfill volume occupied, the study uses the 'critical volumes' method. The latter is no longer used routinely. At the time, it was assumed to represent the relative impact relative to legislative limits and allowed practitioners to aggregate measures of environmental impact for all air or water impacts, respectively.
Financial / economic considerations	No.	N/A.	No.
Social impacts	No.	N/A.	No.
Overall assessment of quality	Fair/Poor.	A relatively concise overview of LCA methodology applied to a comparison of waste management options.	Fair – especially since this study was conducted and reported in 1993.
General comments	This is not an LCA study *per se* that	This is more of an introductory text and	Whilst this study is now arguably too

	compares reuse with recycling. It is a study used to inform discussions regarding an ecotax based on the equivalent quantity of waste arisings associated with refillable packaging compared to recoverable packaging.	a discussion paper. It includes a brief review of a study comparing reuse and recyclable packaging for fresh milk and beer (UBA, 1993), indicating that the authors conclude that there are many factors that affect the outcomes of the findings and hence it is not possible to distinguish between the relative environmental benefits associated with those pack types/systems compared.	old to generate relevant results today, it does nevertheless demonstrate the importance of infrastructure and logistics. The study is not well reported regarding methodology but does contain an enormous amount of graphs showing the results. The authors conclude that the German Packaging Directive was 'on the wrong track' in respect of favouring returnable packaging, highlighting the importance of transport distances as well as incineration as a viable alternative resource/waste management option.

Annex B

Overview of Life Cycle Assessment (LCA) and Life Cycle Thinking

Life Cycle Assessment

The International Organisation for Standardisation (ISO) defines Life Cycle Assessment (LCA) as, 'Compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product system throughout its life cycle.'[2]

The 'life cycle' is defined as, 'Consecutive and interlinked stages of a product system, from raw material acquisition or generation of natural resources to the final disposal.'

LCA methodology is a relatively mature discipline with work having been carried out over the last thirty five years to evolve and develop a methodology now standardised by ISO and used by Government Agencies and many blue chip organisations world wide.

Undertaking – or compiling – an LCA is broken down into a series of discrete stages as follows:

- Goal and scope definition
- Life cycle inventory analysis (LCI)
- Life cycle impact assessment (LCIA)
- Life cycle interpretation

Whilst the above stages are described separately, inevitably, there is a fair degree of iteration between each stage.

Goal and scope definition

Goal and scope definition is where the LCA is planned with users setting the framework for how the study will be undertaken.

Life cycle inventory analysis

Life cycle inventory analysis is where the 'system' (ie those activities under study) is modelled and data gathered and used to compile the data sets for each part of the system modelled. The latter tends to be the most time consuming phase accounting for about 80% of the effort (and costs). Life cycle inventories concentrate on quantifying the use of raw materials and energy as well as the associated releases to air, water and land.

[2] ISO 14040, Environmental Management – Life Cycle Assessment – Principles and Framework (1997)

Life cycle impact assessment
Life cycle impact assessment is where the results of the life cycle inventory analysis are 'converted' into measures of environmental impact; for example, global warming potential; air acidification potential, etc.

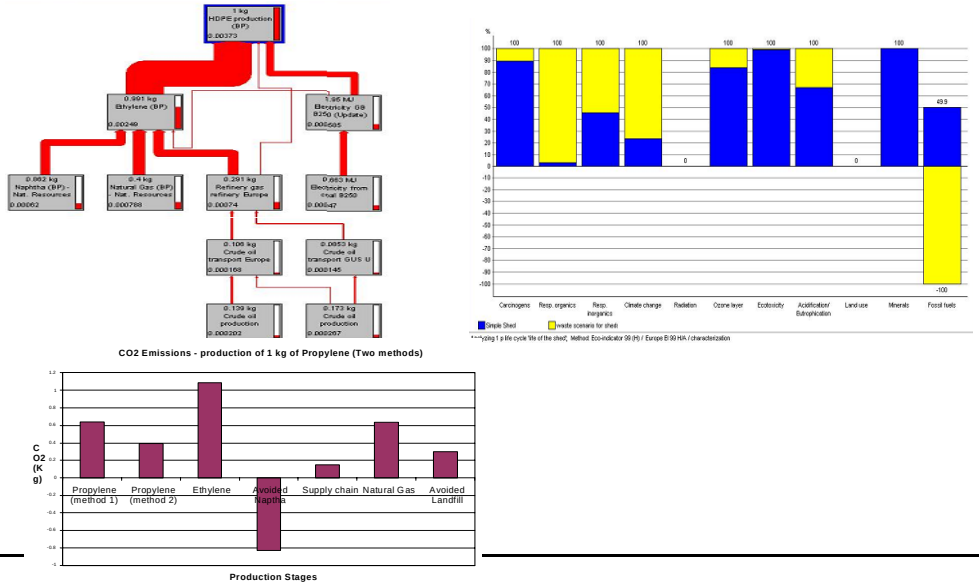
It should be noted that this decreases the number of parameters (data values) considered significantly as well as takes account of *relative* contribution made by different inputs and outputs to the *same* environmental concern. To achieve this, impact assessment potentials are expressed in 'equivalent units' whereby, for instance, all atmospheric releases that contribute to global warming are expressed relative to carbon dioxide; ie [amount of release] x [factor] to convert a given quantity of a gas that contributes to global warming into a carbon dioxide equivalent. Obviously, once this step has been carried out, all greenhouse gases can then be added up to give a total carbon dioxide equivalent.

Life cycle interpretation
Life cycle interpretation is the stage when the results compiled are examined with a view to fulfilling the aims of the study. Interestingly, an enormous amount of additional useful information can come out of an LCA. One of the main advantages of the interpretation phase is that it allows users to identify those activities that might be targeted to bring about the greatest improvement in performance.

When comparing alternative scenarios, it can also allow users to determine, for instance, whether they are potentially shifting environmental impacts from one part of a life cycle to another or even from one medium to another.

A further benefit of the life cycle methodology is that it also provides a sense of magnitude. For example, policy tends to focus almost predominantly on end of life issues (ie waste management) yet when one considers Directives such as those focussing on End of Life Vehicles (ELVs) or Waste from Electrical and Electronic Equipment (WEEE), by adopting a life cycle approach it becomes apparent that all our efforts are actually concentrating on approximately 1% of the total environmental impacts of the whole life of a car or an item of electrical equipment only. Respecting that in these instances, 80 to 90% of the environmental impacts are associated with the use phase, then this demonstrates that targeting the use phase is where improvements in environmental performance are most likely to yield the greatest results.

Figure 1 - Illustration of life cycle mapping and data capture / presentation



Life Cycle Thinking
Life Cycle Thinking is a relatively new term that in reality is poorly defined. Life Cycle Thinking is often associated with Integrated Product Policy since European Commission communications on Integrated Product Policy refer to Life Cycle Thinking as a way of helping to make more informed decisions.

Life Cycle Thinking is an approach or a way of thinking that draws upon elements of an LCA methodology to help support decision making. This might include the identification of those activities that comprise the 'life cycle' as well as, for instance, *selected* environmental inputs and outputs and associated impacts that occur throughout the life cycle. The latter information tends to be presented in the form of 'indicators' as distinct from the data and results generated when compiling an LCA that tend to be mathematically linked to a precise measure of performance or functionality for the 'product or service system' examined.

Use of LCA and Life Cycle Thinking to inform decision making
The main applications of LCA and Life Cycle Thinking include:

- Benchmarking;
- Material selection;
- Comparison of alternative products/services;
- Systems analysis (eg comparison of alternative scenarios for handling and disposal of waste arisings);
- Product and process improvement;
- Investment decisions;
- Policy setting;
- Supporting communication (eg marketing and reporting).

Figure 2 - Example: a targeted approach to greenhouse gas reduction using a life cycle approach (fictional data only).