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LCA sensitivity and eco-efficiency analyses of beverage packaging systems

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LCA sensitivity analysis and eco-efficiency study

Background
In a former study for the Association of European Producers of Steel for Packaging (APEAL) TNO analysed and evaluated a number of European key studies regarding the Life Cycle Analysis of several one-way and refillable beverage-packaging systems. To be able to compare these LCA key-studies the results were recalculated to the same basic comparison unit (the packaging of 1000 litres beverage) and the environmental impact figures were made comparable.
Seven studies were evaluated in more detail. A comparison of these key-studies showed remarkable differences with regard to several parameters (see ***Sensitivity analysis***)

TNO suggested to perform an in-depth sensitivity analysis to establish the sensitivity of several packaging systems to variations of (a selection of) the researched parameters.
Another recommendation of the TNO study performed in 2001 was to carry out a sensitivity analysis for key parameters and an eco-efficiency analysis, integrating environmental impact and chain costs of a beverage-packaging system. APEAL has commissioned TNO Environment, Energy and Process Innovation (TNO-MEP) to carry out the sensitivity analysis and the eco-efficiency analysis[1]. An expert panel reviewed the study with respect to the physical data and an LCA expert (PriceWaterhouseCoopers, Paris) reviewed the study considering the methodology.

The UBA II study[2] is a study commissioned by the German federal environmental agency (UBA) and is used as a reference because it has the advantage over the other evaluated studies that the process sheets, including data, used in the LCA are most complete and transparent. Therefore this LCA can be reconstructed and applied as a base case. The environmental effects of the beverage-packaging systems were calculated from the system characterisations given in UBA II. Therefore the data quality of UBA II has an impact on the final LCA results

Given the scope of the LCA sensitivity analysis some adaptations to the UBA II study had to be made:
- As the allocation method used in the UBA II study was not transparent enough to be fully reconstructed, it was replaced by another allocation method;
- The German DSD packaging waste system was replaced by a system more appropriate for the European situation;

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1 TNO-MEP, 2002, LCA sensitivity and eco-efficiency analyses of beverage packaging systems. Internal report for APEAL.

2 Plincke, E. et al, 2000; Ökobilanz für Getränckeverpackungen II; Endbericht zu Phase I; Prognos, IFEU, GVM und Pack Force im Auftrag Forschungsvorhaben 296 92 504 Umweltbundesamtes, Berlin.

– Use of electricity and heat was based on the European data from the ETH database[1];
– The impact assessment was based on the CML methodology[2].

Beverage-packaging systems

This research has been limited to packaging volumes of 0.33 l (see Table I). However, not all packaging systems used in the UBA II study were using this volume. Therefore recalculations to the 0.33 l volume have been made under the assumption that the mass of the primary packaging changed proportionally to the change in volume. The mass of the secondary packaging was not recalculated for the change in volume of the primary packaging and is calculated on the basis of the functional unit of 1000 l beverage to be packed.

Table I Beverage-packaging systems used in the sensitivity analysis.

Type of system	Packaging system	Contents
One-way	Steel can (SteelCan33)	0.33 l
	Aluminium can (AluCan3)	0.33 l
	Glass bottle (GlassEW33)	0.33 l
	PET bottle (PETEW33)	0.33 l *
	Beverage carton (Carton 33)	0.33***
Refillable	Glass bottle (GlassMW33)	0.33 l
	PET bottle (PETMW33)	0.33 l **

* Based on data measured by TNO of 0.33 l PET bottle for fruit drinks.

** Based on one-way and refillable glass bottle of 0.33 l, 1.0 l PET bottle from the UBA II study and measurement by TNO on a 0.33 l one-way PET bottle.

*** Based on the 1 l beverage carton for non carbonated beverages and measurements on two types of 0.25 l beverage cartons.

Objectives of the study

The main objective of the study is to show that regulators have to be cautious when they intend to apply the results of LCA calculations of different packaging systems as a basis for discriminating
several systems and related materials. The results of LCA sensitivity analyses and eco-efficiency analyses will support this statement.

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1 Bollens, et al, 1996 Ökoinventare von Energiesystemen, Grundlagen für den ökologischen Vergleich von Energiesystemen und den Einbezug von Energiesystemen in ökobilanzen für die Schweiz. 3. Auflage.

2 CML stands for Centrum Milieukunde Leiden, the Centre of Environmental Science of the Leiden University, The Netherlands. CML has developed a method for life cycle impact assessment. Heijungs, R. (ed.), 1992, milieugerichte levenscyclusanalyses van produkten: Handleiding en Achtergronden, Nationaal Onderzoekprogramma Hergebruik van Afvalstoffen [NOH], CML, Leiden.

The goal of the LCA sensitivity analysis is to establish for the selected beverage-packaging systems:
1. The parameters for which a system is the most sensitive and the parameters for which it is insensitive;
2. The effect of the variation in the values of these parameters on the significance of observed differences between beverage-packaging systems.

The eco-efficiency study will be carried out for the systems used in the sensitivity analysis. The main goal of this study is twofold:
1. Assess, using LCA and LCC results, the eco-efficiency of a selected number of both one-way and refillable beverage-packaging systems;
2. Evaluate the observed differences in eco-efficiency thereby taking the results of the sensitivity analysis into consideration.

Selection of environmental themes/categories

The impact assessment method used here is based on the CML1 method, one of the most detailed and widely accepted methods in Europe. The environmental themes mostly considered are given in Table II.

Table II *Overview of environmental themes and categories. The environmental impact for the **Bold** themes have been studied for this study.*

Environmental theme	**Abbreviation**
Mineral Resources Depletion Potential	ADP
Acidification Potential	AP
Aquatic Eco toxicity Potential	**ECA**
Energy Resources Depletion Potential	EDP
Global Warming Potential	**GWP**
Human Toxicity Potential	**HT**
Nitrification Potential	NP
Ozone Depletion Potential	**ODP**
Photochemical Ozone Creation Potential	**POCP**
Special categories	
Final Waste	FW
Toxic final Waste (hazardous waste)	TW
Cumulative energy requirement	**ENER**

It is known from past experiences that the mineral resources and the energy resources depletion potential appear in practice not to decrease with ongoing extraction of resources. This is due to the increasing efficiency of resources extraction and the discovery of new resource locations. Inclusion of ADP and EDP is thus discussable and these themes are therefore not included. The themes “acidification potential” and “nitrification potential” are not included in the presented results, as the (political) importance of these themes has diminished during the last years. As final waste and toxic waste are special categories of which the environmental effects of the waste treatment are already included in the environmental themes, these categories are not further used here. Otherwise a kind of double counting may arise. Finally, as the reduction of the use of energy is still an important political item throughout Europe, the results for this theme have been included.

LCA sensitivity analysis

A sensitivity analysis aims to indicate which parameters of a beverage-packaging system have the strongest influence on the results of an LCA when the parameters are varied between certain limits. In a typical application of an LCA sensitivity analysis technique, only one parameter is varied at one time. This will give insight in the effects of varying this single parameter. However, there are two main disadvantages following this approach. Firstly, parameters may be affected by the value of another parameter, for instance the waste scenario that is chosen for the system influences the effect of varying the percentage of input of recycled material. Therefore, an incomplete outcome is the result.
Secondly, the total variation within a system cannot be obtained. The size of the variation within a system is of importance when comparing the system with another system for which the range of variation is also known.
The method followed here is close to a random simulation (Monte Carlo approach). Ideally the parameters used in the sensitivity analysis would be varied according to their stochastic variation.

The in-depth sensitivity analysis to establish the sensitivity of the selected packaging systems is concentrated on the following parameters:

- Weight of the primary packaging;
- Transport distance between filler and retailer or point of sale;
- Percentage of secondary material used;
- Trip rate (no. of cycles per bottle) for refillable systems;
- Trip rate (no. of cycles per pallet) for secondary packaging;
- Waste disposal option (percentage waste to incineration versus percentage to landfill);
- Composition of beverage carton.

The major assumptions for the analysis are:

1. The variation in input data of the systems as mass, trip rate et cetera lies between plus and minus 50% of the UBA II / TNO reference value. This artificial range represents the limits of two times the standard deviation;
2. In case the means of two systems do not fall outside each other’s range the differences between the systems are regarded as insignificant.

The assumption that the variation in input data is plus or minus 50% of the reference value has been made, as stochastic data on the distribution of the values of a parameter did not exist. This assumption has an important impact

on the size of the range within the results of a system lie, and thus on the significance of the observed differences between systems.

In the sensitivity analysis the effects of varying a set of important parameters for each system was analysed. The main results and conclusions that can be drawn from this part of the study are given hereafter.

General results

- As the differences that arise between systems in LCA results are not always large enough to be significant, it is better to identify the occurrence of groups of beverage-packaging systems. These groups include the systems for which the individual means fall within the range of one or more of the other systems ranges. An approach in establishing groups of beverage-packaging systems would be more realistic than discriminating between individual systems. True statistic data are preferred to perform a sensitivity analysis;
- The primary packaging of the one-way systems largely determines the environmental burden of the systems for nearly all the environmental themes. Transport and the secondary packaging are of lesser importance.
- Both primary packaging and transport determine the environmental impact of the refillable bottles. The secondary packaging is of a lesser importance.

Results and conclusions with respect to the six environmental themes

In Figures I up to VI the possible variation (range) around the reference value for each of the seven packaging systems is shown for the six selected environmental themes.

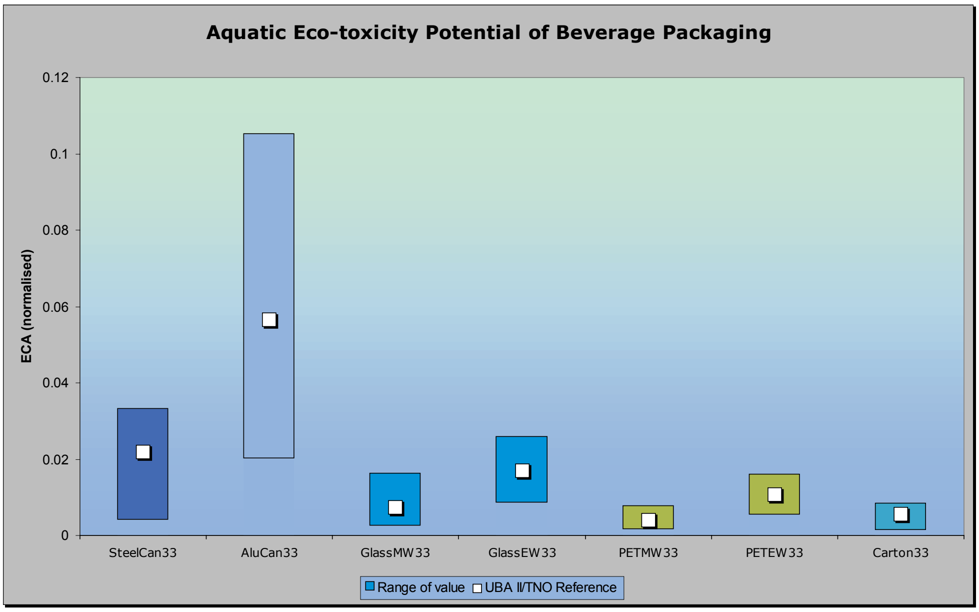

Figure I Variation in aquatic eco-toxicity potential.

– Considering the aquatic eco-toxicity potential the aluminium can forms, more or less, a separate group with a relative high value. The main cause for this is the release of PAHs (Polycyclic Aromatic Hydrocarbons) related to the production of aluminium. The remaining six systems form generally speaking one group with relative low values.

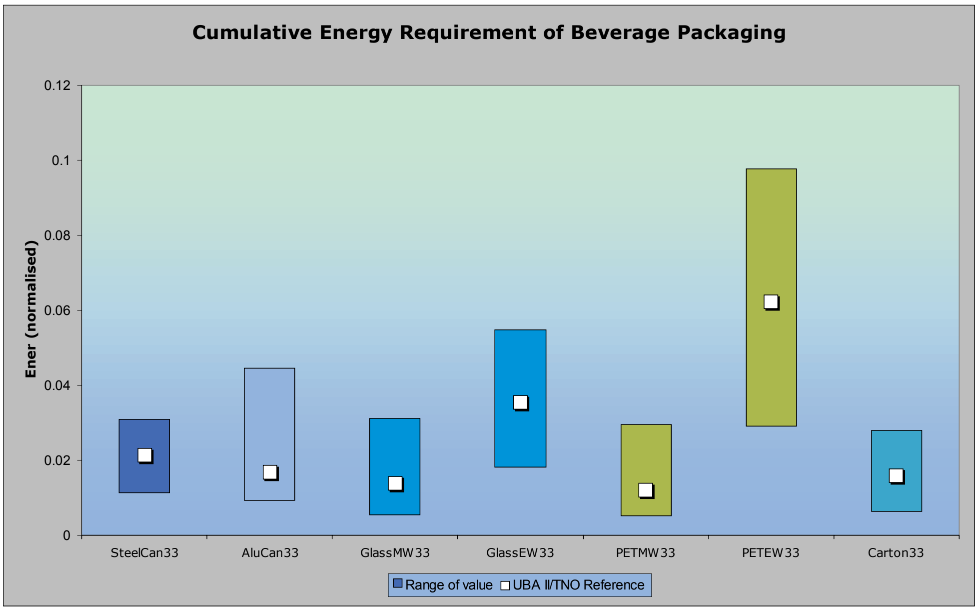

Figure II Variation in cumulative energy requirement.

– At least two groups can be distinguished. One group formed by both the cans, the beverage carton, the one-way glass bottle and both the refillable bottles with relatively low values and a group consisting of the one-way PET bottle with relatively high values.
– The relatively high score for the one-way PET bottle is mainly caused by the use of crude oil as a raw material for the production of PET (feedstock energy) and by the use of electricity in the PET production process. Due to the reduced use of PET in the refillable PET system its score is markedly lower than that of the one-way bottle.

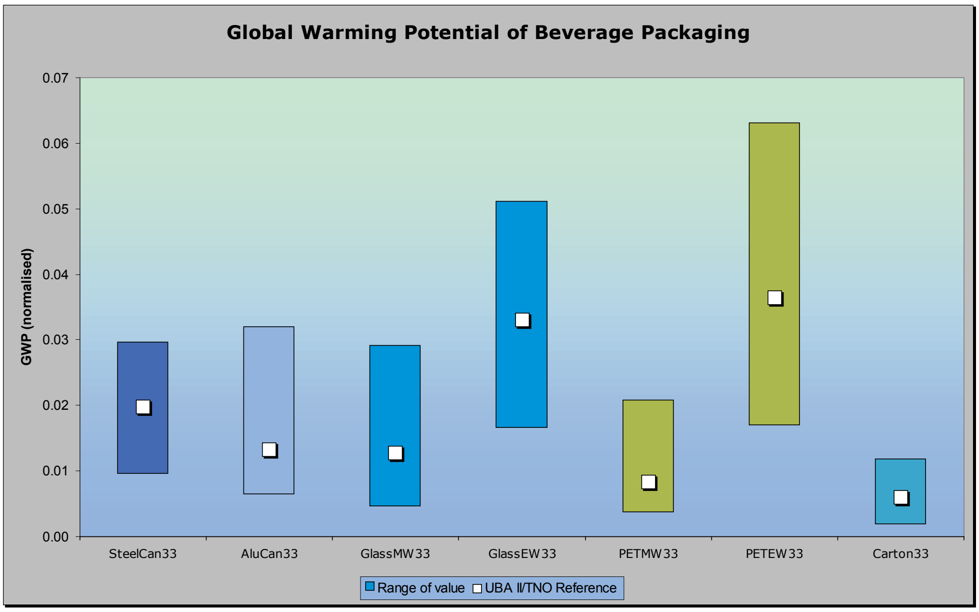

Figure III Variation in global warming potential.

- Two groups appear for the global warming potential: one with relatively high scores consisting of the one-way bottles and one with relatively low scores.
- The high score for the PET one-way bottle is mainly caused by the release of CO_2 related to the energy usage for the production of the PET bottle. For the one-way glass bottle, the score is high due to the release of CO_2 related to the energy for the production of glass.

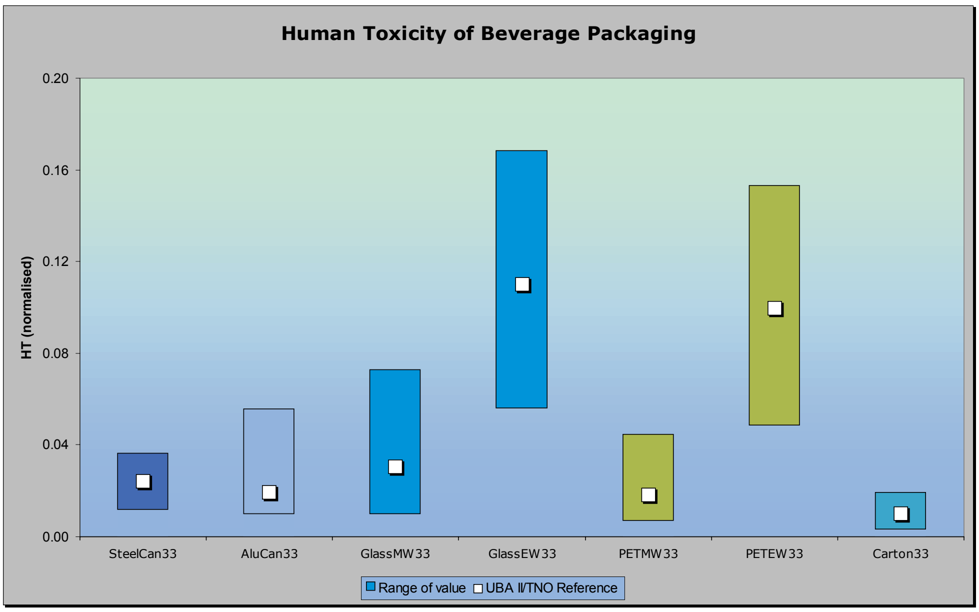

Figure IV Variation in human toxicity.

– Two systems emerge for the human toxicity theme: The one-way PET bottle and the one-way glass bottle form the group with relatively high scores. The one-way glass bottle scores high due to the release of NO_x and SO_x in the air related to electricity production processes used for glass production. The score of the one-way PET bottle is mainly caused by the release of NO_x and SO_x related to the energy usage for the production of the PET bottle.

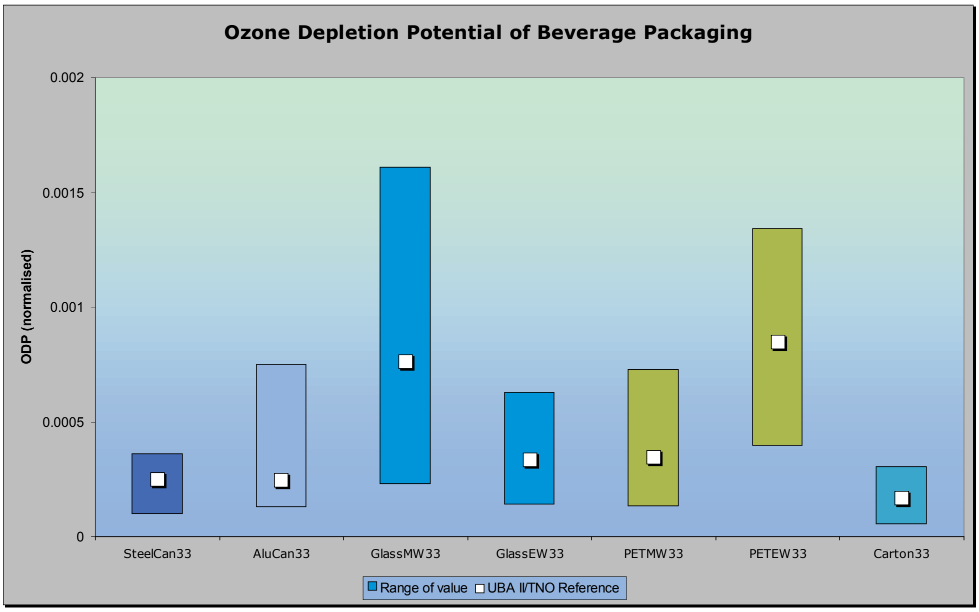

Figure V Variation in ozone depletion potential.

– Again two systems stand out as a group with relatively high scores. The one-way PET and the refillable glass bottle form this group. The score of the PET bottle is mainly caused by the release of Halon 1301 related to the energy use for the production of the PET bottle. For the glass bottle, the score is mainly caused by the emission of Halon-1301 related to production of diesel fuel for transportation.

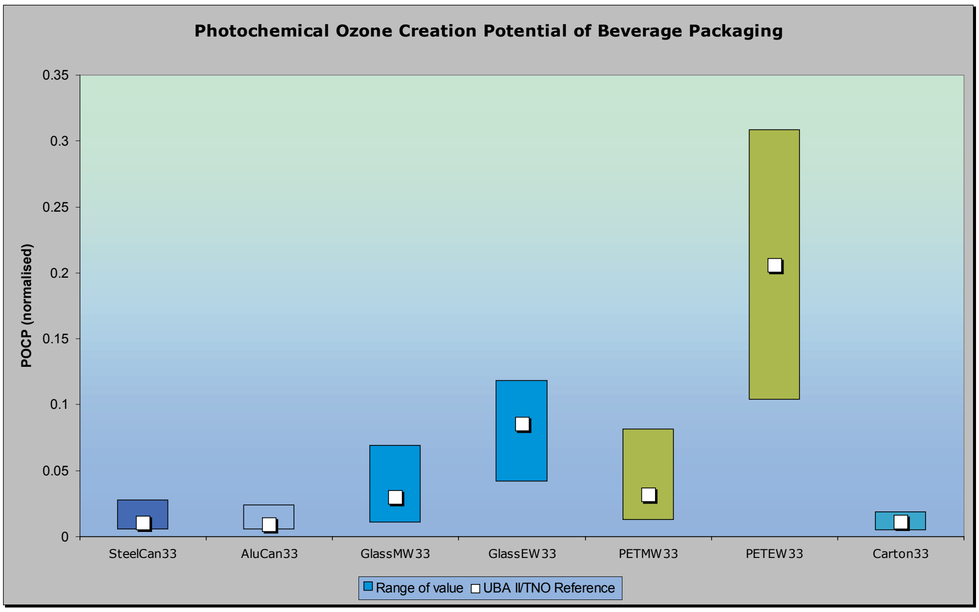

Figure VI Variation in photochemical ozone creation potential.

– The last theme, photochemical ozone creation potential, shows three groups. The one-way PET bottle forms the group with the highest value. The main cause is the release of the emission of non-methane VOC (volatile organic compounds) related to the production of PET. The one-way glass bottle forms an intermediate group, the release of non-methane VOC related to the production of glass is the main cause for this score. The remaining five systems form a group with relative low values.

Results on sensitivity of the seven packaging systems

– All systems are sensitive (range + or – 30 to 40%) to changes in the mass of the primary packaging (see Figure VII).

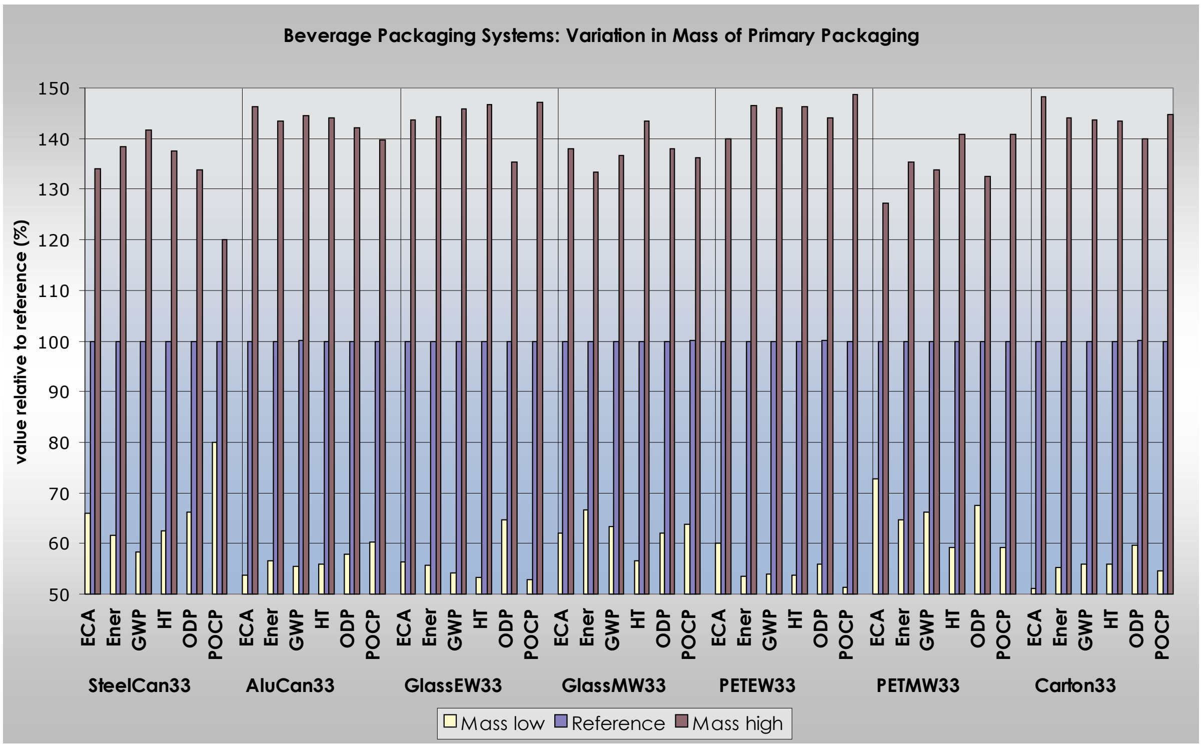

Figure VII *Sensitivity of the beverage-packaging systems for the variation in the mass of the primary packaging. Mass low = Reference – 50%, Mass high = Reference + 50%.*

– The steel can and the two one-way bottles are sensitive (sensitivity between 75 and 150%) to changes in all parameters for the six selected environmental themes. The aluminium can is clearly the most sensitive system (sensitivity over 150%).

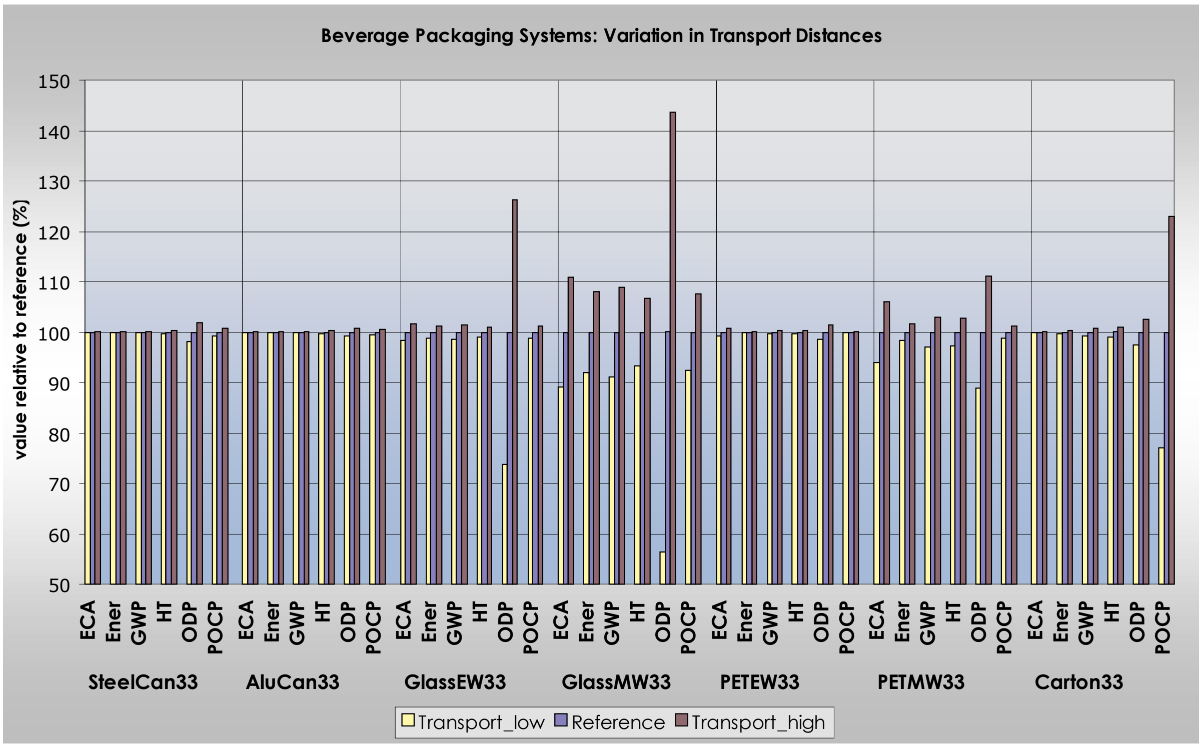

Figure VIII Sensitivity of the beverage-packaging systems for the variation in transport distance. Transport low = Reference – 50%, Transport high = Reference + 50%.

– The one-way systems and the refillable PET bottle appear to be highly insensitive (range of + or – 0 to 5%) for variation in the transport distance between filler and the retailer or point of sale (see Figure VIII). The refillable glass bottle is more sensitive (range of + or – 14%). The refillable PET bottle has, despite its insensitivity, a higher sensitivity than the one-way PET bottle as the effect of transport in the total life cycle is larger;

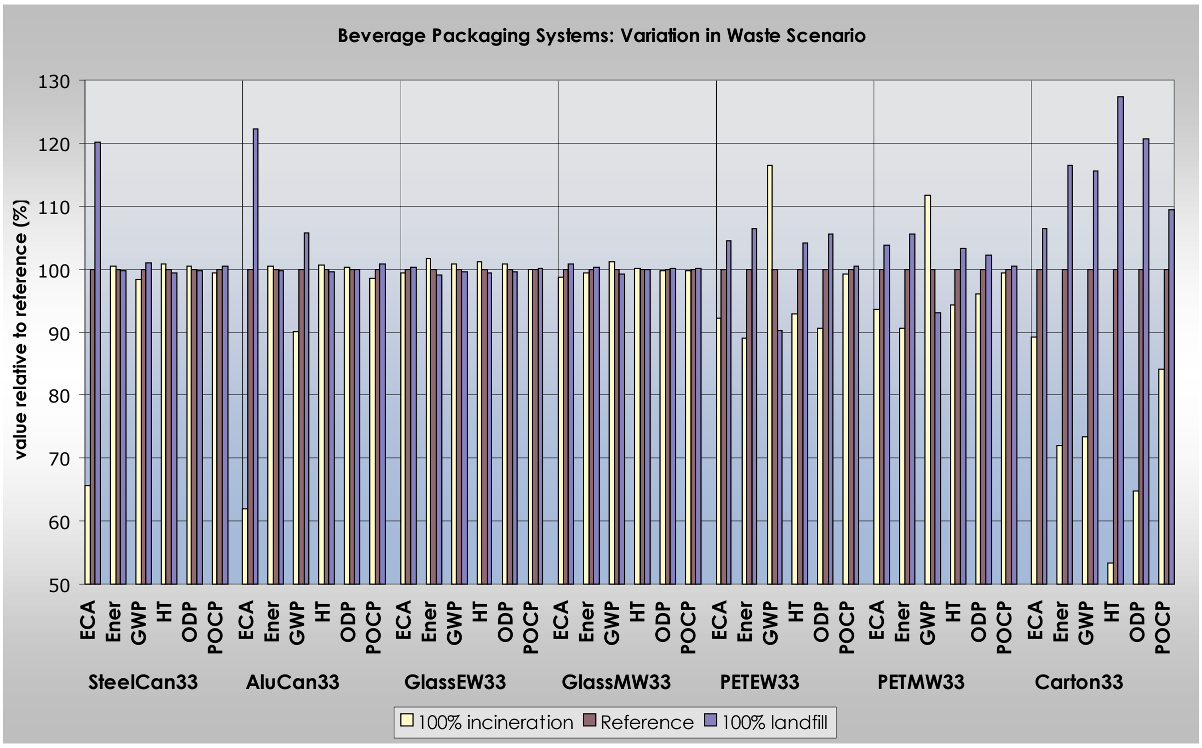

Figure IX *Sensitivity of the beverage-packaging systems for the variation in waste scenario. Reference = 63% landfill, 37% incineration.*

– Variation in the waste scenario (from 100% incineration to 100% landfill, see Figure IX) may cause for one theme (i.e. POCP) an increase in the score, while for another theme (i.e. GWP) a decrease can be seen. Both the beverage carton and the aluminium can are, on average, slightly sensitive (range + or – 5 to 25%) to changes in waste scenario;

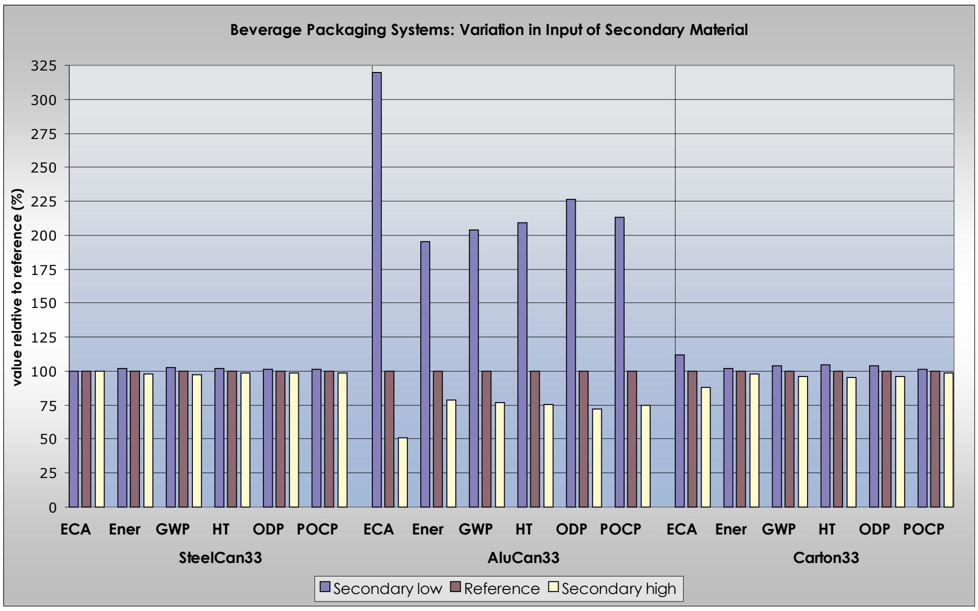

Figure X *Sensitivity of the one-way cans and the carton for the variation in input of recycled material. Secondary low = Reference – 50%, Secondary high = Reference + 50%.*

– The aluminium can is very sensitive (range + or - 78%) to a lowering in the percentage of secondary aluminium used in the can body (see Figure X). The steel can and the beverage carton, however, are highly insensitive (range + or – 1 to 5% or less) to changes in the input of respectively secondary steel and secondary aluminium;

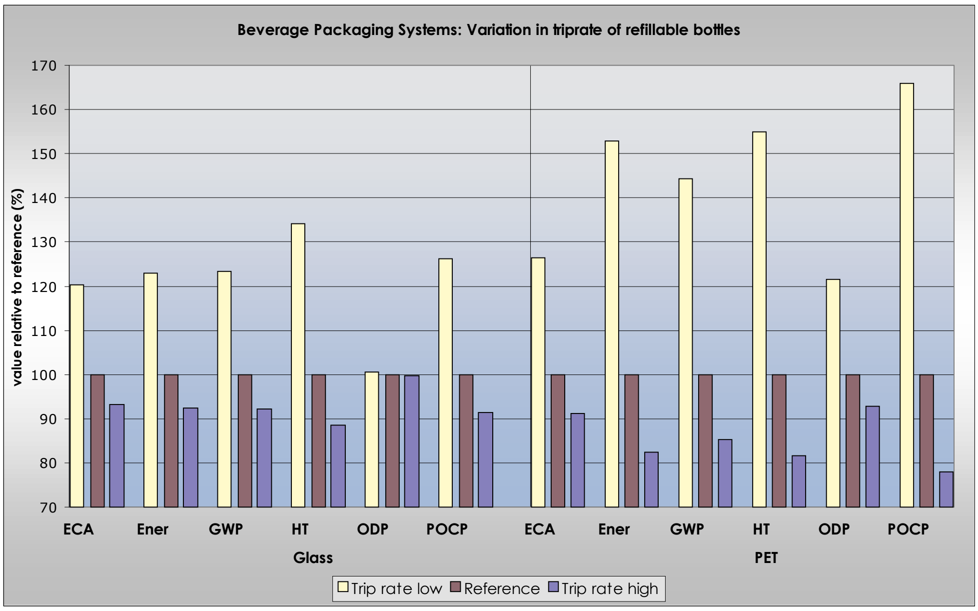

Figure XI *Sensitivity of the refillable bottles for the variation in the number of cycles a bottle makes. Trip rate low = 10.5 cycles, Reference = 21 cycles, Trip rate high = 31.5 cycles.*

– Changes in the number of cycles of a refillable bottle lead to changes in the environmental impact. The refillable bottles are sensitive (range + or – 14 to 30% or less). Decreasing the number of cycles leads to an increased environmental impact. Increasing the number of cycles has an opposite effect. The effect of an increase in cycles is however less strong than a decrease.

Life Cycle Costing

Life Cycle Costing (LCC) was not included in the UBA study, and cost data appeared to be scarce. However, at the end of 2000 another LCA study by GUA and IFIP was presented for the Austrian market, which also included the economic effects (costs) of several 0.5 to 1.5 l one-way and refillable systems. Costs for the packaging machinery, buildings and labour were excluded from the costs data that have been used here.

It has been assumed that the reduction of the volume of a can, bottle or beverage carton from its volume in the GUA and IFIP study to the volume of 0.33 l used in our study leads to a proportional decrease in costs. It is however likely that small volumes have relatively higher costs per volume than larger ones. As this factor is not known and because all systems are treated in the same way no attempt was made to make a correction in costs per unit.

The GUA and IFIP study is a study commissioned by the Austrian Federal Environmental Agency, the Austrian Beverage Federation and the Ministry of Economic Affairs, and is used as a reference as it is the only study that contains detailed life cycle costs data. Therefore these costs data can be reconstructed and applied as a base case. The costs effects of the beverage-packaging systems (see Figure XII) were calculated from the system characterisations given in the GUA and IFIP study. This means that the data quality of these systems has an impact on the final LCC results.

Results and conclusions with respect to system costs

In Figure XII, the possible variation (range) around the reference value for each of the seven packaging systems is shown.

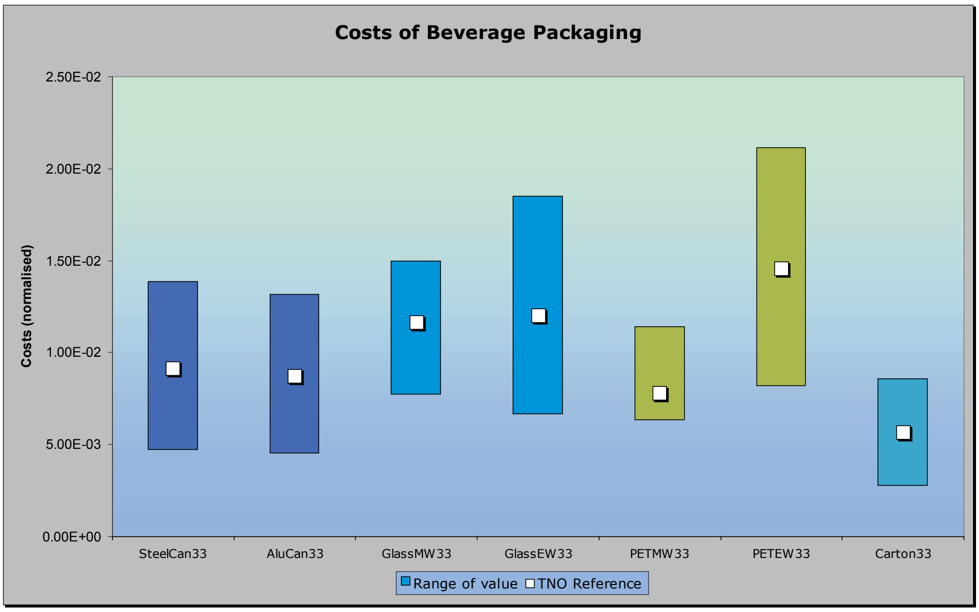

Figure XII Variation in costs of beverage-packaging systems.

Eco-efficiency

The combined presentation of the integral environmental impact score and the total costs score is called the eco-efficiency graph. To obtain the eco-efficiency of a system, the normalised costs[1] and the normalised[2] and evaluated value of the environmental impact are scaled by setting the maximum occurring value of each category to 1 while keeping a zero value to 0. So on each axis one finds at least one of the studied systems.

1 Normalised costs: Life cycle costs are related to the Gross Domestic Product of the EU-15.

2 Normalised environmental impact: the scores of the environmental themes (of beverage packaging systems) are related to the score for the EU-15 in 1995.

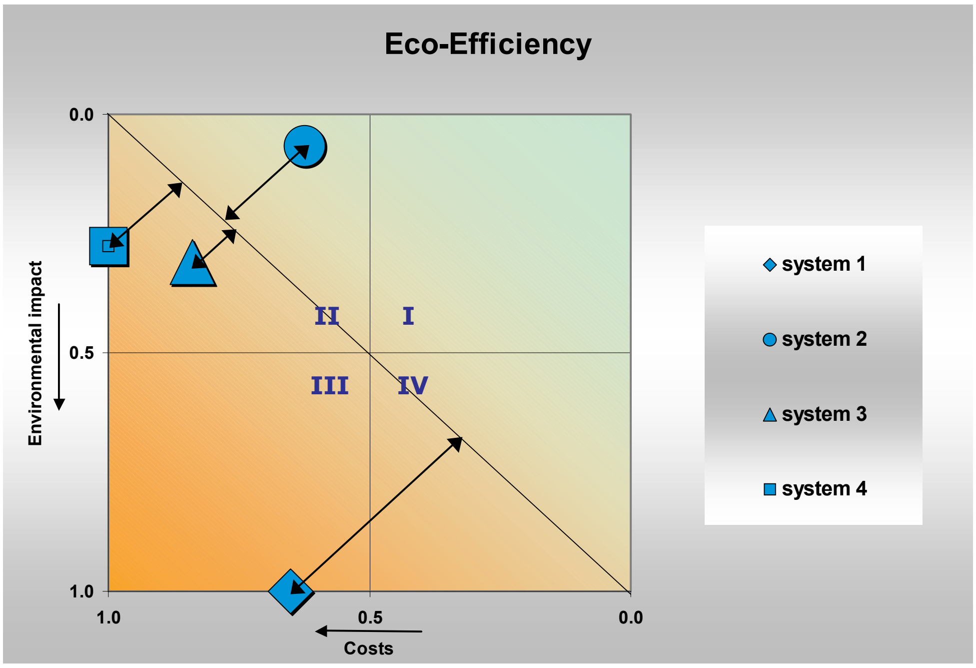

Figure XIII Basic eco-efficiency graph.

Both scores can now be judged to their position in the graph, which can be divided in 4 squares. Figure XIII gives a theoretical example of the defined portfolio.
The meaning of the 4 squares in the portfolio is roughly as follows:
Square I: relatively low costs, relatively low environmental impact;
Square II: relatively high costs, relatively low environmental impact;
Square III: relatively high costs, relatively high environmental impact;
Square IV: relatively low costs, relatively high environmental impact.

In principle the diagonal is an important reference line in the portfolio. Points with the same distance perpendicular to the line have the same eco-efficiency. Large distances above the diagonal indicate a relatively high eco-efficiency; large distances below the line indicate a small eco-efficiency.

As from Figure XII it is clear that the systems form more or less one group, differences in eco-efficiency that are caused by differences in costs cannot be seen as significant. Only significant differences in environmental impact will lead to significant differences in eco-efficiency.

It appears from Figure XIV in which the range of values has been used to calculate the eco-efficiency, that two eco-efficiency groups can be observed. One group is formed by the steel and aluminium can, both the refillable bottles and the beverage carton, which has a relative high eco-efficiency and one group formed by the one-way PET and glass bottles with a relative low eco-efficiency. It is also clear that within these two groups overlap is present.

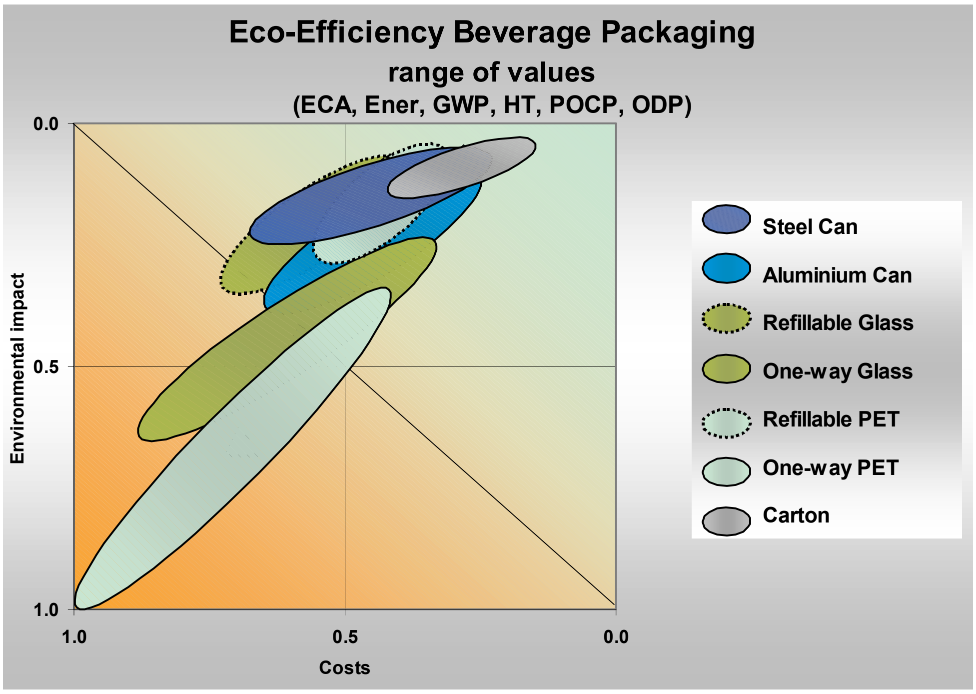

Figure XIV Range of eco-efficiency for the seven beverage-packaging systems. Note that the ranges overlap in eco-efficiency.

Additionally the trip rate of refillable bottles is shown as an illustration of the effect of the variation in a single key parameter. The trip rate is an important parameter as it affects the environmental impact of the refillable bottles. The effect of lowering the trip rate from 21 to circa 11 cycles is shown in Figure XV. In this figure only the reference values (based on UBA II, GUA & IFIP and TNO data) are shown.

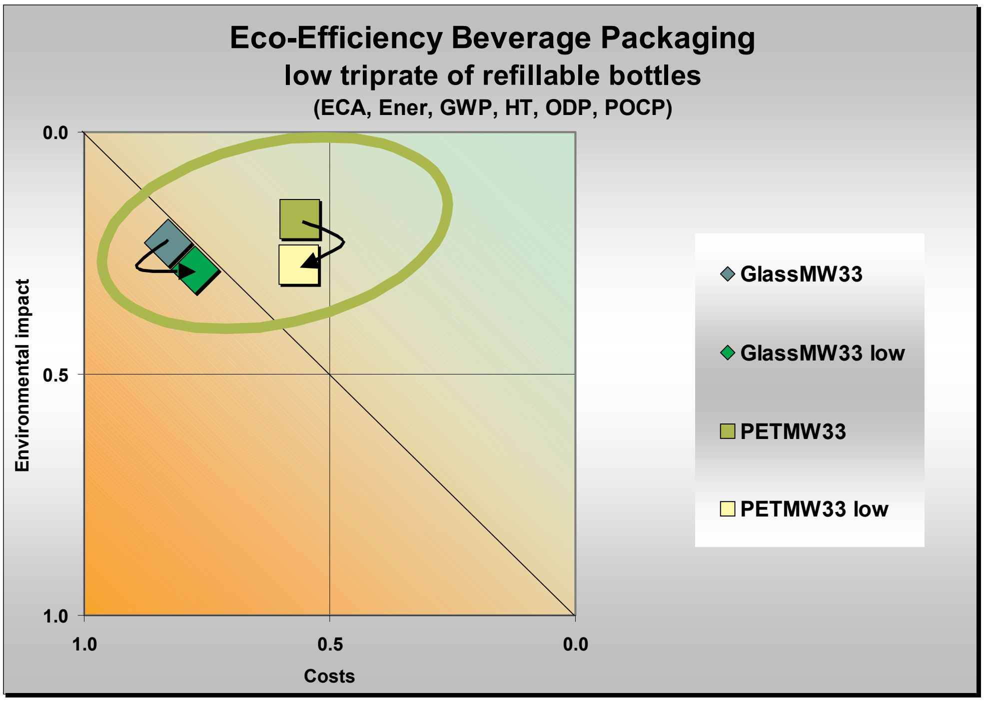

Figure XV *The effect of lowering the trip rate of the refillable bottles from 21 to 11 cycles on the eco-efficiency.*

Lowering the number of cycles for a refillable bottle gives rise to a lower eco-efficiency of the refillable bottles. However, the bottles remain in the group with the highest eco-efficiency.

Main conclusions

1. The conclusions of the LCA and eco-efficiency sensitivity analyses clearly demonstrate that the borderline between ecologically favourable and unfavourable packaging is very tenuous.
2. Discrimination between concepts and materials thus has to be avoided when the results of an in-depth sensitivity analyses are not available.
3. With regard to the results of the study, especially the LCA sensitivity analysis, the outcome of the LCA impact will be strongly influenced by allocation aspects (for instance the inclusion of recycling and the valuation of the input of secondary materials) and by the quality of the applied data.

Main recommendations

1. As the differences that are observed between individual systems may not be significant, decision makers have to be cautious to apply the results of an LCA study in political or legislative areas. The conclusions drawn from an LCA must be based on a thorough sensitivity analysis and an analysis of the quality of the LCA model and the data used in it;
2. With regard to the results and the related conclusions it is recommendable to perform a new European LCA study for the packaging of 1000 litres

beverages. Allocation rules and data quality have to be the main aspects when such a study will take place.

3. Because of the discussions about data quality it is recommendable to use certified data to assure a known level of quality. This means that a certification procedure for the LCI (Life Cycle Inventory) has to be developed.

Authentication

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Names and establishments to which part of the research was put out to contract:

Date upon which, or period in which, the research took place:

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