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Life Cycle Assessment of PET (Polyethylene Terephthalate) bottles and other packaging alternatives

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Abstract.

Various alternative packagings for carbonated soft drink products in Germany were compared in a large-scale LCA. Interest was focused on a PET bottle which was to be materially recycled in a closed loop as far as possible. It was examined to what extent such a system can be considered ecologically equivalent to comparable systems, e.g. the returnable glass bottle. A special task of the LCA was to provide a clear representation of the many indicators from the inventory analysis and the impact assessment. Sensitivity analyses were used to examine the influence of changes in the initial parameters and of improvements in the systems.

Keywords: beverage packaging systems; PET; polyethylene terephthalate; PETCYCLE; LCA; Life Cycle Assessment; returnable bottles

1 Introduction

1.1 Background and Objective

Intensive discussion is underway in Germany at the present time on the environmental compatibility of beverage packagings. The background to this is the "Ordinance on prevention of packaging wastes", which as early as in 1991 was a response by environmental policy to the growing quantities of waste in Germany. In this ordinance the hierarchy "*prevention comes before recycling comes before waste disposal"* was stipulated and reusable packaging was favoured. As regards disposable beverage packaging, the ordinance stipulates that this must in principle be subjected to a deposit charge of 0.50 DM. It can only be exempted from this obligation as long as the quota of returnable packagings on the German market does not fall below 20 % for milk and below altogether 72 % for beer, mineral water, juices, refreshment beverages and wine. The deposit, which is to be charged to the final consumer, is intended to ensure that the manufacturers take back the disposable packagings.

In the meantime the figures for returnable packagings have dropped below 72 % in Germany (BMU 2000) and the introduction of this deposit charge is now threatened for disposable packagings (Table 1). However, for "ecologically beneficial beverage packagings" § 9 of the ordinance offers the possibility of exemptions from the obligation to levy a charge. One example of this is the tube bag for milk made of polyethylene. It is classified as "ecologically advantageous", since the

Table 1: Returnable quota in beverage packagings in Germany. Source: BMU (2000).

	1992	1994	1996	1998
Beverages total (excl. milk)	**73.54 %**	**72.87 %**	**72.21 %**	**70.13 %**
- Mineral water	90.25 %	89.53 %	88.68 %	87.44 %
- Refreshment beverages with CO_2	76.54 %	76.66 %	77.50 %	77.02 %
- Fruit juices and other beverages without CO_2	38.98 %	38.76 %	37.93 %	35.66 %
- Beer	82.37 %	81.03 %	79.02 %	76.14 %
Milk	28.33 %	26.94 %	30.60 %	25.0 %
Quota of PE tube packaging for milk	1.53 %	2.25 %	10.50 %	9.7 %

German Environmental Protection Agency (UBA) had a large-scale LCA of beverage packagings carried out from 1992 to 1995 (Projektgemeinschaft Lebenswegbilanzen 1995). Accordingly, its significance in the market improved substantially after 1995 (Table 1).

For this reason the packaging manufacturers have a strong interest in having their packaging systems graded as "ecologically beneficial", in order to circumvent a compulsory deposit. The life cycle assessment plays a crucial role here, since in national policy it is the basis for assessing whether a packaging system is to be considered as environmentally sound or not.

For this reason the development joint venture PETCYCLE Entwicklungs- und Arbeitsgemeinschaft GmbH & Co. KG issued an order for an LCA to ifeu-Institut Heidelberg, which was completed in 1999 and presented to the Federal Ministry for the Environment in March 2000 (Ostermayer et al. 1999). PETCYCLE is an alliance of beverage packers, machine manufacturers for installations processing the plastic polyethylene terephthalate (PET), and companies in the packaging industry who plan to set up a "PET material recycling system" in Germany.

The task of the LCA was to compare packagings for mineral water and lemonades with each other and to examine in particular a new PET packaging system known as the PET material recycling system. It was to be ascertained whether and under what general conditions a PET material recycling system is ecologically equivalent to the established glass and PET returnable systems, and can thus be considered as *ecologically beneficial* beverage packaging and be excepted from the rules of a compulsory deposit.

The comparison with the 0.7 litre returnable bottle for mineral water, which is widespread in Germany, is particularly important here. About two thirds of the mineral water in Germany is bottled in such "pearl-glass" bottles (so called because of the pearl decoration on the bottle). In the public eye and among politicians, this is considered to be a typical returnable system and particularly environmentally sound. The pearl-glass bottle was introduced in 1969 by a combination of German mineral water bottlers - the Genossenschaft Deutscher Brunnen (GDB). In particular it has the advantage of pool forming for empties, i.e. the bottles can be exchanged. Each bottler takes back bottles of other firms as well as his own and fills them again. In this way unnecessary transport operations can be saved.

However, at the present time there are many efforts to replace this pearl-glass bottle. Weighing 590 grams, it is almost just as heavy as the material with which it is filled (700 g, see Table 2). It is not compatible with Euro-pallets. Many firms need a special design for their marketing today and would like to deviate from the standard bottle. Leading mineral water firms therefore introduced new glass bottles into the German market, in some cases with conspicuous designs such as e.g. Carolinen-Brunnen in Bielefeld with a bottle designed by Luigi Colani. However, these individual packagings are tied to the relevant bottler as returnable systems and require corresponding logistic arrangements for return of the empties.

That is why light-weight PET bottles have become very important. However, the use of returnable PET bottles involves major investments for the bottlers, since the empty bottles have to be examined for contamination. using costly techniques. Many small and medium-sized firms cannot afford these investments. Changes in beverage packagings can therefore involve concentration effects in the beverage industry and lead to weakening of the many medium-sized firms in Germany, who in particular serve a regional market with short transport distances. This latter effect would involve major impacts for the environment.

The concept of the "PET material recycling system", on the other hand, proposes that the PET bottles should be materially recycled after being used (once only) and the material should be re-used for bottle production (Figure 1). By contrast with the classic disposable systems, the PET used would be run in nearly closed material recycling systems and the typical system disadvantage of disposable systems - increased generation of waste - could be avoided. A deposit charge system would be an incentive for customers to return the bottles and thus ensure high return quotas. The segregated returned PET would be treated in conditioning centres and be delivered to the bottlers again as preforms or as finished bottles. The precondition for this system is a well-functioning, full-scale collection and reconditioning structure. Similar systems already exist in Switzerland and in Sweden, though there the recycled PET is not sent straight back to bottle production but is used in other high-grade products such as e.g. textile fibres. However, in the PET material recycling system a genuine recycling circuit is aimed at.

All beverage packaging systems currently being discussed or used have advantages and disadvantages, as well as potential for improvement. Generally, the material PET has substantial weight advantages over glass systems, e.g. in the PET returnable system, which is also reflected in the LCA. The concept of "material recycling" unites two further advantages. The bottles can be produced with an individual design by the relevant bottler without this involving long return transport paths. At the same time, the bottle weights can be reduced substantially again by comparison with PET returnable bottles, since the bottles need not be suitable for several turn-arounds.

1.2 General conditions

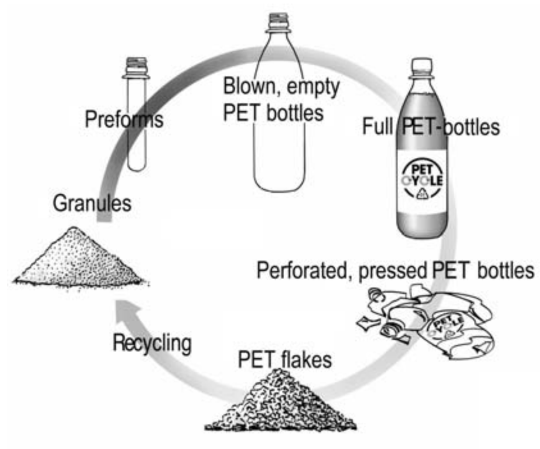
The LCA commissioned was to be oriented strongly to the methodology of studies which were drawn up in parallel by Prognos AG Basel and ifeu-Institut on behalf of German companies or the UBA, and was to correspond to the latest ISO standards (Prognos/ifeu 1999). In addition a critical review procedure with renowned experts from the LCA sector was planned. Thus the study was among the first LCAs published in Germany to correspond to the ISO standard.

The quantity of packaging needed to provide 1,000 litres of beverage from the mineral water and lemonade sector was taken as a comparison standard, as a "functional unit", of the LCA. This makes it

Table 2: Description of the beverage packaging systems for stock purchases taken into account in the study

System name	Brief description / important features					
	Volume	**Bottle material**	**packaging**	**bottle weight**	**cap**	**Return quota**
Glass ret. 0.7 l *C*	0,7 l	Glass-Returnable	HDPE-crate	590 g	Alu-/HDPE-screw cap	99.5 %
PET-MR 1 l *C*	1 l	PET-Material recycling	HDPE-crate	46 g	PP-screw cap	99 %
PET-. MR 1 l *C*	1 l	PET-Material recycling	HDPE-crate	33 g	PP-screw cap	99 %
PET- MR 1 l *T*	1 l	PET-Material recycling	HDPE-tray	33 g	PP-screw cap	90 %
PET-ret. 1 l *C*	1 l	PET-Returnable	HDPE-crate	71 g	PP-screw cap	99 %
L-Glass-ret. 1 l *C*	1 l	Light glass-Returnable	HDPE-crate	490g	Alu-/HDPE-screw cap	99.5%
PET- MR 1,5 l *C*	1,5 l	PET-Material recycling	HDPE-crate	38 g	PP-screw cap	99 %
PET- MR 1,5 l *T*	1,5 l	PET-Material recycling	HDPE-tray	38 g	PP-screw cap	95 %
PET-ret. 1,5 l *C*	1,5 l	PET-Returnable	HDPE-crate	103 g	PP-screw cap	99 %

Figure 1: The recycling of "PET material recycling bottles"



possible to carry out a basic comparison of beverage packagings with different volumes. Despite this, a distinction was made between systems from stock-keeping sectors and systems for immediate consumption, since consumer requirements differ. In addition to the actual beverage packaging made of glass or PET, the labels and capsules as well as the transport packaging (bottle crate or tray) needed for 1,000 litres of bottled material were taken into account.

The systems considered are beverage packagings which are either already established in the market or have already been developed and successfully tested. Altogether 14 different systems made of glass or PET were compared, including 5 systems for immediate consumption with very small volumes (0.33 and 0.5 litres) and 9 systems for stocking purchases with volumes of 0.7 litres and more. Only the results for the stock purchase sector are described below (Table 2).

The "life cycles" of the product systems with the various stages from procurement of raw materials to waste disposal were described as process chains. The production and waste disposal of the beverage packagings themselves, of the transport packagings (e.g. crates, trays or wooden pallets), or important operating and auxiliary materials were taken into account, as well as the actual filling process and distribution and redistribution. The provision of the infrastructure (e.g. the machines or means of conveyance) and the production of the relevant material to be bottled, in other words the beverage, were not taken into account, inasmuch as they were independent of the packaging system.

Alongside the process chain, a product system is only defined by a number of assumptions in the life cycle, e.g. distribution distances or recycling quotas. These are relevant for the results for the product system and must always be taken into account for comparison purposes. In other words, the entire production, consumption and waste disposal system of the product, including the so-called system parameters, must be described. In the case of assumptions on the life cycle, either real processes and system parameters were taken as a basis, or plausible assumptions were used, such as are used in the LCA for the UBA.

One crucial stipulation within LCAs is the question of how the secondary raw materials are used or generated. Generally, an attempt is made to use secondary raw materials - in as far as they conform to real conditions - in a closed loop, e.g. in glass fragment use, the glass from broken glass bottles is used for production of new

Table 3: Impact categories taken into account and the indicators used for them

Resources	Cumulative Energy Demand CED Crude oil resources equivalent value Process water consumption
Greenhouse effect	Global Warming Potential GWP
Acidification	Acidification Potential AcP
Eutrophication	Eutrophication Potential NP
Photo-oxidant creation	POCP or NCPOCP
Noise	Lorry mileage
Human toxicity	Cancer Risk Potential CRP
Nature space used up	Landfill area Wood consumption

bottles. In the case of the new PET material recycling system, however, assumptions had to be made. It was assumed that 50 % secondary PET can be used again in PET bottle production. Results of surveys and experience compiled by the party commissioning the study indicate that this is a conservative assumption and that possibly even higher values can be achieved in future (TNO 1996; Welle und Franz, 1998). However, an assessment of this assumption lies outside the scope of examination of this LCA.

The remaining secondary PET which leaves the closed loop will - according to the assumption of this study - be passed on for high-grade material recycling. A credit is normally issued to the PET beverage bottles for this. In the case of secondary PET which leaves the system, 90 % of the substituted primary PET/ amorphous is credited, since at the present time the market can absorb the secondary PET without any problems. However, such credits affect the results. For this reason it was decided to calculate the systems once without credits (so-called cut-off account) and once with credits (net account). This illustrates the influence of more or less arbitrary credit rulings. The influence of such assumptions on the results was also examined and discussed with sensitivity calculations.

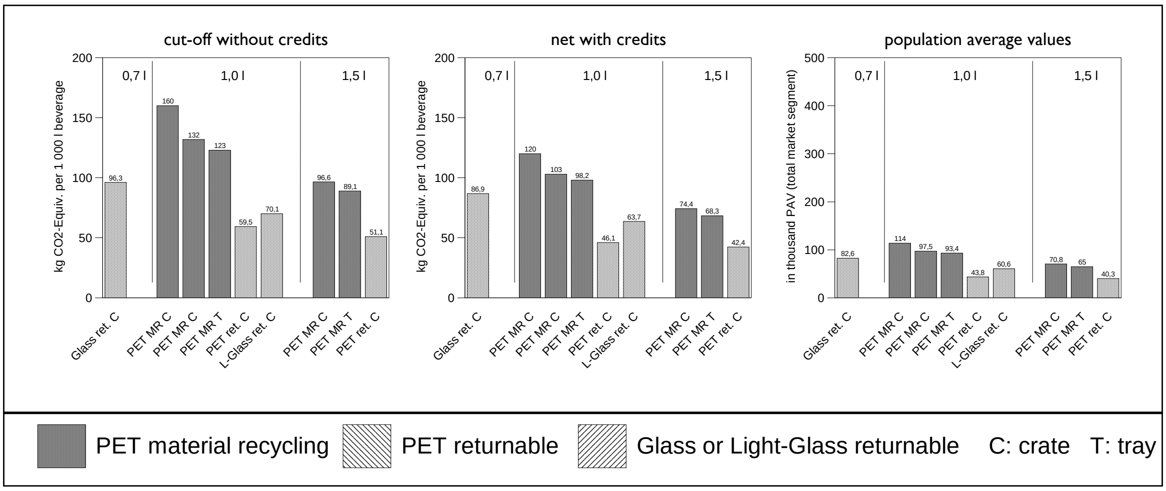
2 Procedure

When drawing up the inventory analysis, the actual core of an LCA, data categories oriented firstly to the availability of data for the various sub-processes and also to an altogether justifiable data balance were taken into consideration. Data insecurities in some areas were examined by sensitivity calculations as to their relevance. It was derived from this that results only differ significantly in system comparisons if the difference exceeds 20 %. Secondly, data categories needed to determine the most important environmental impacts for the investigation were included.

Since according to the defined objective the study is to discuss the question of whether the PET material recycling bottle is ecologically equivalent to other returnable beverage packaging systems, ecological impact categories were selected which on the one hand illustrate the ecological relevance of beverage packaging systems, and on the other hand correspond to the public and political priorities set in Germany. The selected impact categories and the indicators to be used are compiled in Table 3.

Both the inventory analysis and the impact analysis with the aggregation of data to form impact indicators were conducted with the aid of the Umberto® software.

Figure 2: Results for Global Warming Potential in the cut-off-system (left), in the net system with credit for secondary PET (middle) and normalised in population equivalents (right)



Umberto offers comfortable possible ways of describing complex product systems as material flow networks and process chains and of analysing the results (Schmidt et al. 1997, Möller et al. 2000). The life cycles of the systems are mapped as a material flow network which consists of up to 200 individual process modules. Dealing with multiple product processes or difficult allocations, drawing up scenarios and conducting relevance analyses are facilitated by the software. The material flows - broken down via various network levels - can be visualised as Sankey diagrams. The impact assessment is carried out on the basis of the input and output balance of the systems and is partly distinguished by life cycle segments. This makes a sector analysis possible, i.e. the question as to which areas make the highest contribution to the relevant impact indicators can be answered.

The final evaluation is based on two further steps. In a standardising step the results were presented on a different scale. For this the results of the LCA on the market potentially possible, i.e. on the entire market segment for mineral water and lemonades, were calculated for each impact indicator. Thus it was assumed that the entire market is serviced by the relevant packaging system. This would be the maximum influence which such a packaging system could exert on the relevant impact indicator in Germany. This value was set in relation to the overall value of an impact indicator in Germany and expressed in terms of population average values (PAV). In other words, a PAV value of e.g. 1000 for GWP means that the relevant system would contribute as a maximum just as much to GWP in Germany as 1000 inhabitants if the entire market were equipped with the system.

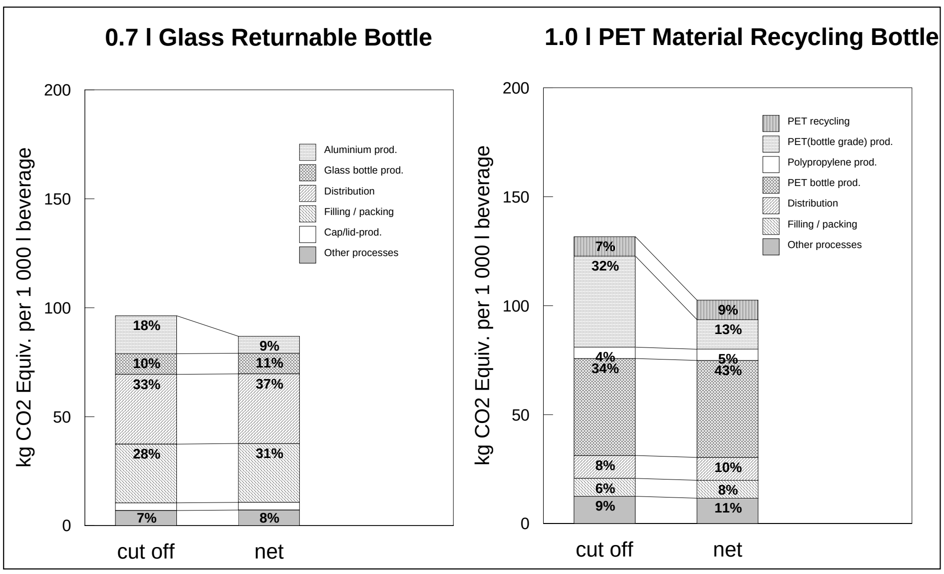
In a second step sensitivities were calculated in which variations of altogether 14 system parameters or input data were examined for their impact on the results of the impact analysis. The result of these sensitivity calculations was an optimised scenario, taking into account the currently realistic technical and economic general conditions. The conclusions for this study resulted from this.

3 Results

Figure 2 shows the graduated procedure on the basis of a calculated impact indicator, in this case the Global Warming Potential. The various systems for the stock purchase sector are first compared without the use of credits (cut-off). Then the credits for secondary materials are taken into account (net), and finally the data are standardised as population average values, extrapolated to cover the entire market segment.

This shows on the one hand the influence of the credit method used. It is pos-

Figure 3: Contributions of the life cycle segments or processes to the Global Warming Potential in the two systems "Glass ret. 0.7 l C“ und "PET MR 1 l C“



sible to examine whether the credits lead to a change in conclusions, e.g. in the ranking of systems, and these are thus artefacts of the calculations. On the other hand, the PAV presentation clearly illustrates the specific importance of the relevant impact category. This study deliberately refrains from offsetting or aggregating different impact categories.

Basically, systems of stock purchasing show strong dependence on the filling volume, which becomes clear as the values decline from left to right. The returnable systems of the same size (hatched bars in the chart) come off much better by comparison with the material recycling systems (filled bars), especially in this impact category.

Figure 3 shows the contributions of the various life cycle sections or processes to the GWP as a so-called sector analysis. For this the two systems of 0.7 l glass returnable bottle and 1.0 l PET material recycling bottle were selected. In the glass returnable system the processes filling/packaging and distribution dominate the results for the GWP. In the case of the PET material recycling system, on the other hand, the PET bottle production and PET production processes dominate.

The sectoral analysis again clearly shows the influence of the credit method between the cut-off and net approaches. In the case of the glass returnable system, the credit produces effects chiefly in the case of aluminium production (for the bottle caps). Other credits play practically no role here. The determining processes of bottling/packing and distribution are not sensitive to system allocations. In the case of the PET material recycling system, the credit method has effects on the process of PET production. The credit for secondary PET farmed out from the system leads to a reduction of the GWP.

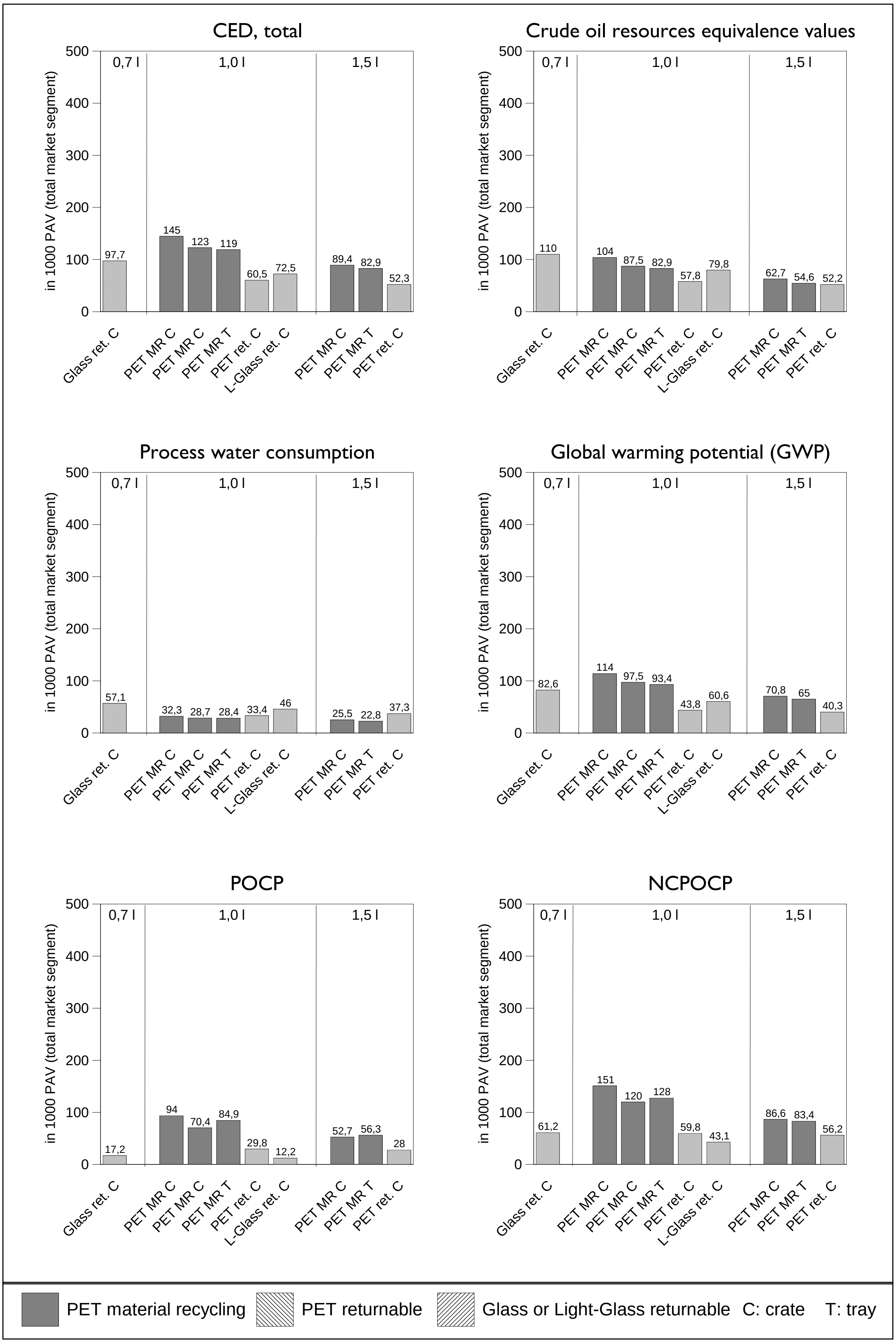
A special challenge in LCAs is to achieve clear presentation of the many quantitative data from the inventory analysis or the impact analysis. Figure 4 shows all 12 impact indicators taken into account for the system of stock purchasing in the form of a so called Hoepfner diagram, which was applied the first time in this study. This allows a fast overview of the behaviour of various indicators with regard to the systems. For the presentation in this paper the PAV values were selected (the cut-off and net values are also documented as Hoepfner diagrams in the final report of the LCA).

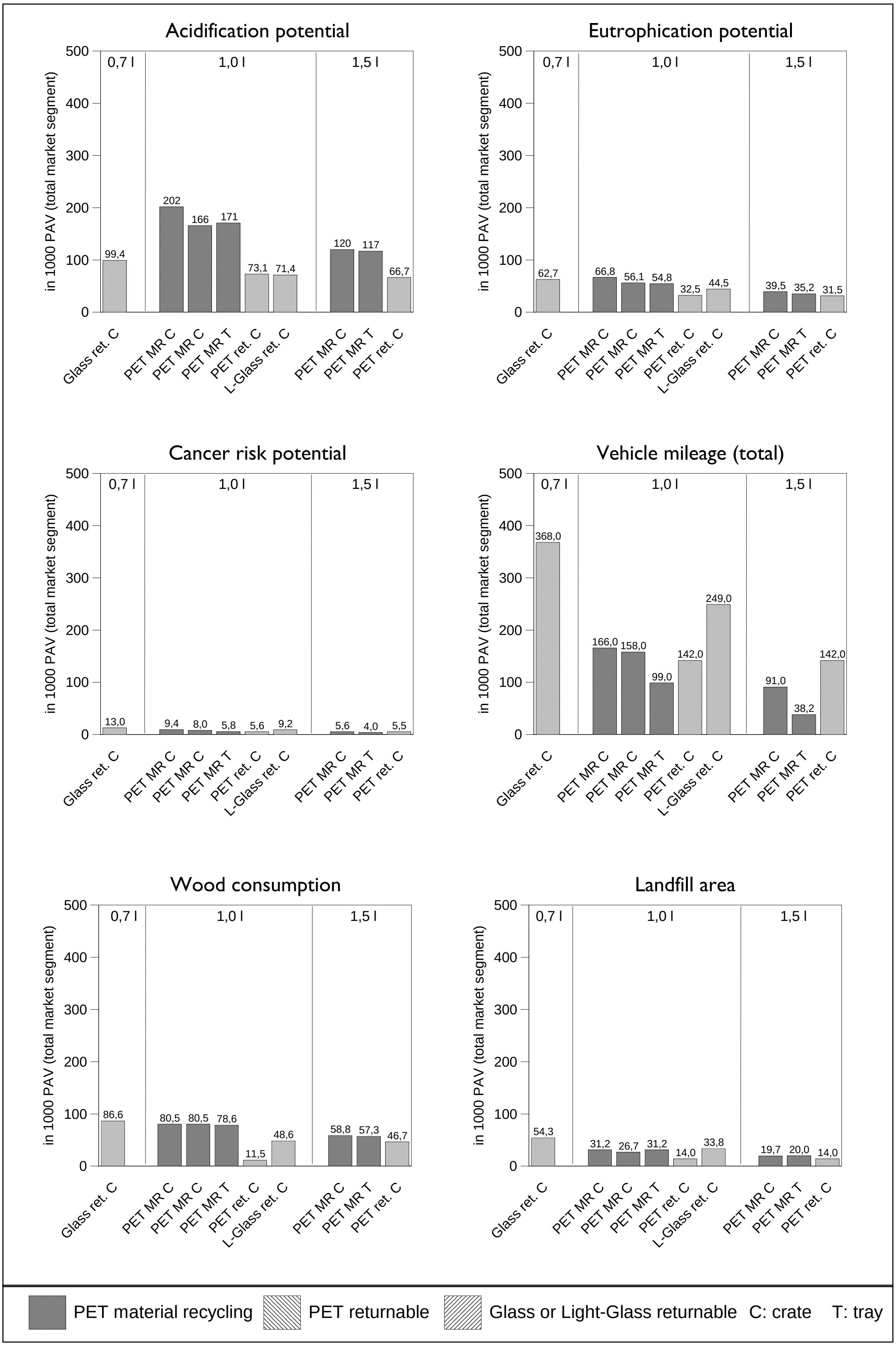
Some indicators show a rather slight specific contribution in the PAV presentation. This applies e.g. for the indicator "cancer risk potential". However, the "landfill area" also makes a lower specific contribution, yet this does not say anything about its ecological relevance. The two indicators "vehicle mileage" and "acidification potential" show the greatest specific contributions with values above 200,000 PAV. Here the ranking of systems runs counter-clockwise: the PET material recycling systems come off best in the vehicle mileage, and worst as regards the acidification potential.

The system of the 0.7 l glass returnable bottle can certainly be considered as a benchmark. This bottle is the most widespread in the market and enjoys the general reputation of being environmentally sound. This comparison is shown in Table 4, whereby the significance threshold of 20 % was selected. It cannot be stated clearly at this point which system comes off as more environmentally sound in the comparison. That depends on the weighting of the various impact categories. Conversely, it is possible to ascertain that at least with the impact indicators CED, POCP and acidification potential, the material recycling system has disadvantages by comparison with the glass returnable bottle. In the case of CED, the PET material recycling system comes off about 25 % worse, in the case of POCP 400 % worse, and in the case of acidification potential 67 % worse. Thus no clear trend, for instance a "winner" or "loser", can be derived from the results.

This situation changes basically if a more modern system such as the PET returnable bottle is taken as a benchmark. The comparison between the PET material recycling bottle and the PET returnable bottle shows a much less favourable result for the material recycling system. The result compiled in Table 5 emerges here. Thus the PET returnable system is clearly the better system. The two systems are only equivalent in a few points.

Figure 4: Comparison of beverage packaging systems for 12 impact indicators, stated as net values (i.e. incl. credit) and in Population Average Values (PAV) (see text)





Acidification potential
in 1000 PAV (total market segment)
0,7 l
1,0 l
1,5 l
99,4
202
166
171
73,1
71,4
120
117
66,7
Glass ret. C
PET MR C
PET MR C
PET MR T
PET ret. C
L-Glass ret. C
PET MR C
PET MR T
PET ret. C
Eutrophication potential
62,7
66,8
56,1
54,8
32,5
44,5
39,5
35,2
31,5
Cancer risk potential
13,0
9,4
8,0
5,8
5,6
9,2
5,6
4,0
5,5
Vehicle mileage (total)
368,0
166,0
158,0
99,0
142,0
249,0
91,0
38,2
142,0
Wood consumption
86,6
80,5
80,5
78,6
11,5
48,6
58,8
57,3
46,7
Landfill area
54,3
31,2
26,7
31,2
14,0
33,8
19,7
20,0
14,0
PET material recycling
PET returnable
Glass or Light-Glass returnable
C: crate
T: tray

4 Interpretation

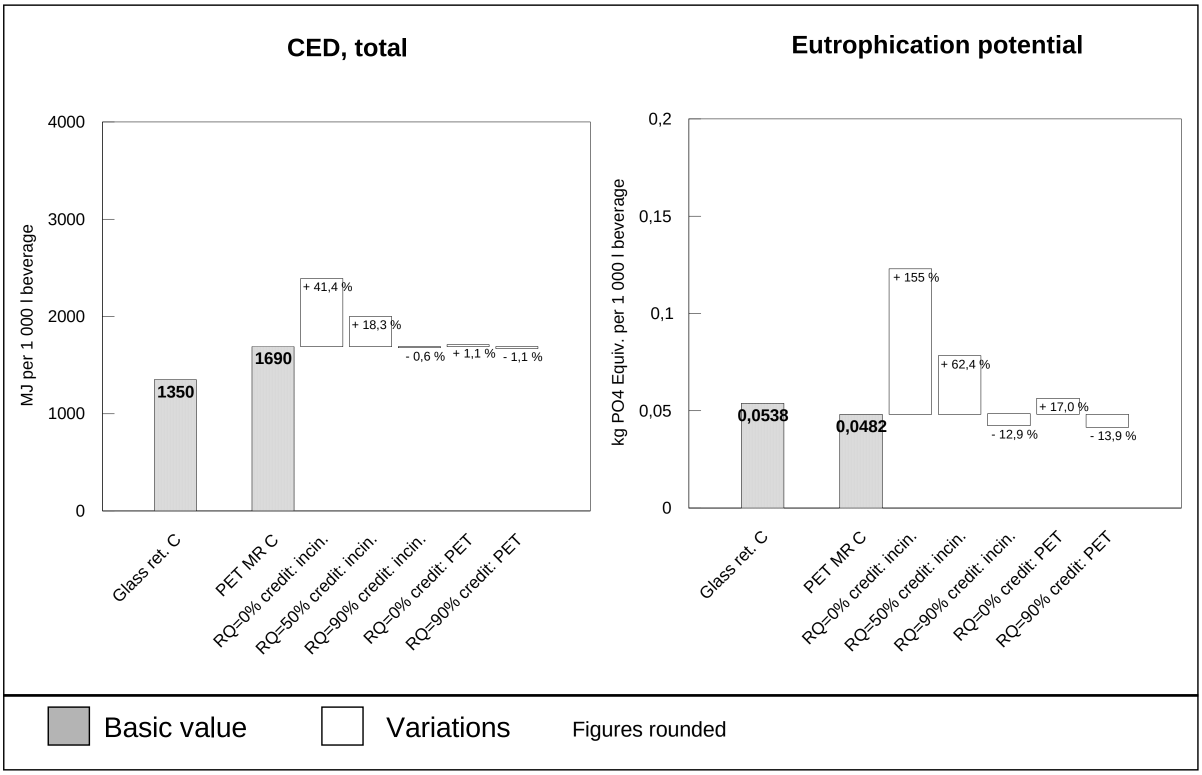
A large number of sensitivity analyses were conducted in the interpretation which are documented in detail in the LCA report and form an essential component of the LCA. On the one hand they show what influence changes on assumptions and system parameters have on the result of the LCA. On the other hand, they serve to identify relevant potential for improvement for the systems considered. One interesting example here is the impact of various recycling quotas and credit methods for PET on the results of the LCA (Figure 5).

The proportion of recycled PET which can technically be used in new bottles cannot be determined reliably at the present time, since PET material recycling systems do not yet have sufficient experience. Therefore a rate of use of 50 % new material in the PET material recycling bottles was assumed for the standard scenarios.

The mode of recycling of the PET material leaving the system boundaries in the open loop has an essential influence on the overall results. It can be assumed that initially nearly all the PET secondary material is recycled in high-grade applications. The long-term recycling paths of the secondary PET can only be determined after the market finds it feet. In the standard systems it is assumed that 90 % of the secondary PET replaces new PET amorphous. The remaining 10 % are not provided with any credit here.

In the sensitivity consideration the recycling quotas and recycling paths are varied. In the worst case, the recycling quota is 0 % and the entire PET material is incinerated, whereby 90 % heavy fuel oil is substituted. In the best case 90 % of the secondary material can be used in the new bottles and remaining PET replaces 90 % PET, amorphously. The result shown in figure 5, specially for the two indicators CED and eutrophication potential, stresses the importance of the recycling quotas and selection of credit procedure. If the PET material is largely recycled (RQ=90 %), then the question of whether the PET farmed out from the system is recycled materially or thermally becomes of secon-

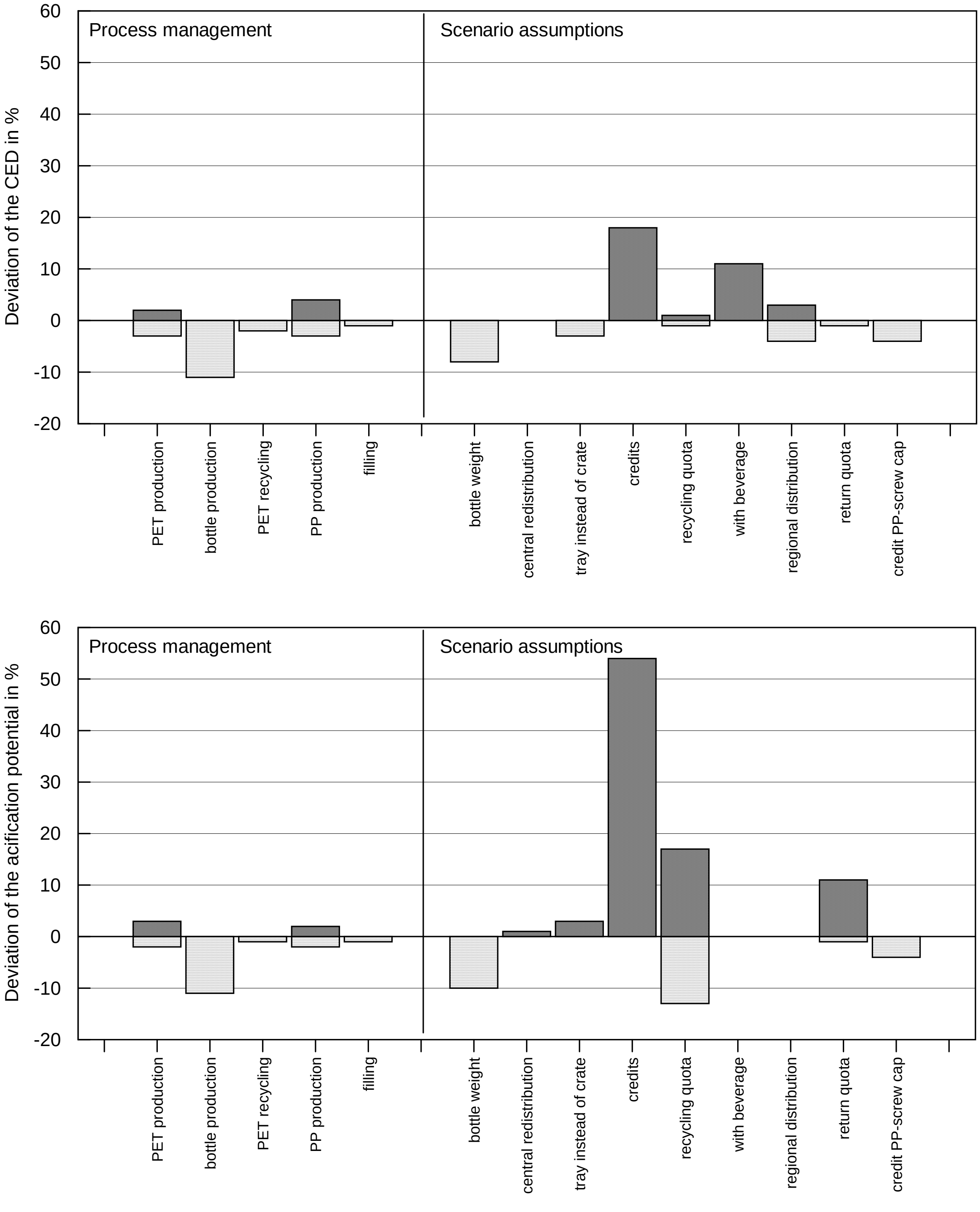
Figure 5: Sensitivity calculation for the credit / recycling quota of secondary PET for the two impact indicators CED and eutrophication. The left bar in the charts is the "Benchmark" of the 0.7-litre glass bottle



dary importance. If secondary PET is not used or is only used with a low percentage for new bottles (closed loop), then the material recycling (in other words a credit for PET amorphous) is definitely preferable to thermal recycling. A low PET recycling component in the system and thermal recycling would make the PET material recycling system appear much worse than in the case of assumptions on the standard scenario.

An overview of the various sensitivities calculated is shown in Figure 6. This is grouped on the basis of sensitivities in the individual process management or scenario assumptions at system level. It is apparent that changed assumptions in the process management - especially in the

Figure 6: Overview of the sensitivity calculations with their impact on the indicators CED and acidification potential in the system "PET-MR 1.0 l C"



direction of improved process management such as are currently technically possible and appear feasible on the market - lead to changes in the two impact indicators, ranging from a few percent to about 10 percent. Changes in the system parameters have an essentially greater influence. Other assumptions regarding the credit for secondary materials or the recycling quotas can influence the results by several 10 percent, and generally even worsen them (= increase of values). These sensitivities are to be assessed individually, i.e. their contribution to results is always only based on the relevant measure; the contributions cannot be added. If the interaction of several measures is to be considered, overall scenarios must be calculated.

Finally, in the sensitivity calculations several assumptions were changed at the same time and such overall scenarios were calculated. In accordance with the objective specified for this examination, attempts were made to set up an optimised scenario for the PET material recycling system. For this a reduced bottle weight, optimised PET bottle production, optimised filling, filling without rinsing and optimised PET recycling were assumed. This scenario can be considered as a scenario using the best technologies currently available on the market and the current possible improvement (e.g. bottle weight). The technologies can be realised today or are already in operation. By comparison with this, assumptions which would be speculative at the present time were omitted. These include in particular improved recycling quotas for PET.

The optimising leads to a clear improvement of the PET material recycling system considered (Table 6). By comparison with the glass system the PET system now comes off as set out below.

The optimised material recycling system only comes off worse than the glass returnable system for the impact indicators POCP and acidification potential. Otherwise it can be considered as equivalent or even better than the glass returnable system. However, this does not represent a final overall assessment, since the ecological relevance of the impact indicators in relation to each other has not been considered in this study.

If one wish to be on the safe side, irrespective of ranking or weighting of the impact categories, and to produce ecological equivalence on the PET material recycling systems and the 0.7 l glass returnable system, the acidification potential has to be reduced further by about 1/3 of the value (starting from the already optimised system). The POCP value has to be reduced by as much as 2/3. The relevant influence parameter is the process of PET production here. With its hydrocarbon emissions it contributes chiefly to the POCP value. In the case of acidification potential, PET production accounts for at least 35 % (net). In addition, the process of bottle production with 30 % is also relevant here. These two processes would have to be improved considerably in order to achieve ecological equivalence in these categories.

The ecological equivalence would then only be effected by comparison with the 0.7 l glass returnable bottle - which is still dominant on the market and generally considered to be environmentally sound. The PET returnable systems would then still have clear advantages over the PET material recycling system.

5. Conclusions

An essential assumption in the packaging systems presented is that the PET material recycling systems are operated with a high share of high-grade recycled PET in a closed loop. Although initial experience in practice on an international basis is available here, an important question focuses on the technical and legal feasibility presumed for this LCA. It was assumed that 50 % recycled PET is used in bottle production. This assumption appears to be altogether plausible, and technically even conservative. However, it is not conclusive for a real system. If the assumption does not materialise, the results change to the detriment of PET material recycling systems.

On the other hand, the contributions of PET production could be reduced further if recycled PET were used in a quasi closed loop system to a greater extent, in other words if recycled PET were used for bottle production again. A further increase of the assumed 50 % would come out clearly in

Table 4: Comparison of results of the “PET material recycling bottle” and the benchmark “pearl-glass bottle”

“PET material recycling 1.0 l crate” compared with “Glass ret. 0.7 l crate”		
better in:	**same in:**	**worse in:**
process water consumption vehicle mileage landfill area	global warming potential eutrophication potential wood consumption	CED POCP acidification potential
Significance threshold:		
> 20 % difference	≤ 20 % difference	> 20 % difference

Table 5: Comparison of results of the “PET material recycling bottle” and the returnable PET bottle

“PET material recycling 1.0 l crate” compared with “PET ret. 1.0 l crate”		
better in:	**same in:**	**worse in:**
	process water consumption vehicle mileage	CED global warming potential POCP acidification potential eutrophication potential wood consumption landfill area
Significance threshold:		
> 20 % difference	≤ 20 % difference	> 20 % difference

Table 6: Comparison of results for an optimised system of the “PET material recycling bottle” and the benchmark “pearl-glass bottle”

“PET material recycling 1.0 l crate optimised” compared with “Glass ret. 0.7 l crate”		
better in:	**same in:**	**worse in:**
process water consumption eutrophication potential vehicle mileage landfill area	CED global warming potential wood consumption	POCP acidification potential
Significance threshold:		
> 20 % difference	≤ 20 % difference	> 20 % difference

favour of the balance for PET material recycling systems. However, it must be considered that for this, high return quotas are necessary and the systems must be designed accordingly. Thus for instance the systems with the tray as transport packing have slight ecological advantages over systems with crates. However, as a result disadvantages could occur in the return quotas, which would have an altogether negative effect.

The attempt to achieve higher recycling use quotas in a closed loop system would also increase the expressive force of the LCA, since it would be possible to largely refrain from applying allocation regulations for secondary materials.

On the basis of these results the following recommendations can be made.

- Design the material recycling systems in such a way that the highest possible return quotas can be realised and these can be sustained in reality. This has a considerable influence on the collection and distribution systems used. For instance tray systems are not advisable.
- The quota for use of recycled material in a closed loop system should be improved as far as possible, i.e. the technical and food law conditions for this should be secured. The target should be a quota of at least 50 %.
- The processes for PET production, PET bottle production, bottling and PET recycling should be optimised further. For this in particular the hydrocarbon emissions and acid creating emissions (SO_2, NO_x) should be reduced.
- The receptacle weights should be reduced further. The 1.0 l bottle weight of 27 g should be the goal.
- The production data for PET bottle-grade granules should be reconsidered and updated.

In the political decision-making process it should be clarified with which packaging systems the PET material recycling system has to be compared and considered ecologically equivalent in order to be treated in the same way as returnable systems.

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