Stiftelsen Østfoldforskning

Environmental Assessment of Non-Refillable-Recyclable and Refillable PET Bottles Used as Packaging for Drinks in Norway

English Version

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Report title:
Environmental Assessment of Non-Refillable-Recyclable and Refillable PET Bottles Used as Packaging for Drinks in Norway.

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Company contact(s): Adrian Stray

Summary:
The project assesses the environmental aspects associated with the use of non-refillable-recyclable compared to the use of refillable PET bottles under the present conditions for refillable bottles: as regards sales volume, bottle size etc. Life-cycle assessment (LCA) methodology based on the ISO standards 14040-43 is used for the analysis performed.
A reference group has been established for the project, consisting of stakeholders from the whole value chain of drinks, from bottle producers to recycling plants, and the independent Norwegian applied research institute STØ. The reference group has been active in data gathering and quality assurance of the data used.

Conclusions

- When taking into account the assumptions and conditions the analyses are based on, in combination with general knowledge about the uncertainty levels in life-cycle assessments (about +/-30%), the two systems can be said to be approximately the same for both environmental and resource aspects.Sensitivity analyses show that the system with non-refillable-recyclable bottles will have significantly (>30%) lower environmental impacts than refillable bottles if:
  - non-refillable bottles were produced with at least 35% recycled material (greenhouse effect, acidification and energy consumption);
  - recycling occurs in Norway (greenhouse effect).
- Sensitivity analyses show that the system with non-refillable-recyclable bottles will have significantly (>30%) higher environmental impacts than refillable bottles if:
  - non-refillable bottles were produced solely from virgin PET material (greenhouse effect, acidification and energy consumption);
  - blowing of non-refillable-recyclable bottles occurs at the bottle/preform producers (all categories);
  - the collection rate for non-refillable-recyclable bottles was lower than 80% (greenhouse effect, acidification and energy consumption).
- Sensitivity analyses show that the following changes in assumptions do not lead to differences between the systems that are greater than the uncertainty level of 30%:
  - introduction of 2 litre bottles for 35% of the production volume in the system with non-refillable-recyclable bottles;
  - changes in trip rate for the refillable bottles.

Keywords: • PET bottles • Environmental assessment • Recycling • LCA/life-cycle assessment	**Confidentiality** **This page:** Open **This report:** Open	**Number of pages** **Report:** 45 **Appendices:** -

Approved
Date:

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Project Manager (sign) **Director of Institute for Environmental Protection** (sign)

Contents

Glossary

Acidification	Acidification results from the atmospheric depositions of acidifying compounds, which is a result of emissions of air pollutants such as ammonia, sulphur oxides and nitrogen oxides. Acidification of terrestrial ecosystem leads, among other changes, to a decrease of pH in the soil solution. Acidification of surface water systems leads to decreased pH, which in turn may lead to disturbances in the ecosystem. However, the effect of acid deposition is site specific, i.e. the sensitivity to acidifying deposition varies between ecosystems. In this study the potential to cause acidification is calculated on the basis of the number of hydrogen ions that can be released per mole of the acidifying substances, using sulphur dioxide as the reference substance (SO_2 equivalents, CML baseline 2000).
BROM	Association of Norwegian Brewers and Soft Drink Producers. Coordinator of the deposit/collection system for refillable bottles.
Collection rate	Proportion of the total number of bottles sold that is returned to the deposit system.
Energy consumption	Consumption of energy resources (for example potential energy, solar, wind, tidal and fossil energy). This gives no direct environmental effects, but changes in the consumption of the different energy carriers can give changes in the other environmental impact categories (greenhouse effect, acidification, eutrophication, photochemical ozone creation potential etc.). Energy consumption is expressed in MJ.
Nett environmental benefit	The sum of the total environmental impacts and total environmental benefits in a defined (recycling) system.
Eutrophication	Eutrophication of an ecosystem involves a transformation from a nutrient poor towards a more nutrient rich state through an excessive input of nutrients, e.g. phosphorous and nitrogen compounds. Eutrophication leads to a change of the chemical conditions which in turn may change the structure and function of the ecosystem, e.g. in surface water systems eutrophication often increases the biomass of some species which lead to an increased oxygen demand when they decompose. The substances which have the potential to contribute to eutrophication are weighted according to their capacity to support the formation of biomass, using oxygen as a reference. The most important sources of emissions of nutrients that can

	contribute to eutrophication in waterways are farming, wastewater from communities, industry, fish farming and nitrogenous emissions from air pollution. Phosphor has more importance for eutrophication in fresh water, whereas nitrogen is the most important nutrient source in saltwater. Visible effects of eutrophication are unclear, discoloured water and overgrowth. Too much algae production in water leads to anaerobic decomposition. This can result in fish death, damage to spawning ground, build up of sludge and toxic water. Eutrophication is expressed as grams O_2 equivalents (CML baseline 2000).
Functional unit (FU)	The functional unit represents a product's performance according to a specific user's requirements. This unit should reflect the product's function and life span. It should, as far as possible, not allow subjective interpretations and should represent the beneficial value of the system. A system can have several functions, and the functional unit shall therefore reflect the function or functions being assessed. All inputs and outputs in the system are related to the functional unit. Example: the functional unit for drink packaging can be the amount of packaging needed to distribute 1000 litres of drinks to the customer.
Global warming potential (GWP)/ global climate change/ greenhouse effect	The chemical composition of the atmosphere is one of the most important factors that influence the climate on Earth. The atmosphere is mostly composed of nitrogen and oxygen, but also contains so-called greenhouse gasses. These **gases** allow most of the energy from the sun to pass through, which comes in the form of short wavelength radiation, but at the same time slowing down the returning radiation from the Earth (in the form of infrared long wave heat radiation). The increased concentration of greenhouse gasses thus leads to an increase in the temperature in the lower levels of the atmosphere, called the troposphere. The most important natural greenhouse gases are steam, carbon dioxide (CO_2) and methane (CH_4). These gases have their natural cycle within the atmosphere, or between the atmosphere and the sea, soil or biosphere. Human activity has lead to emissions that contribute to an increase in concentration of these gases, with the resulting increase in global warming. Altogether, greenhouse gases amount to less than 1 percent of the atmosphere, but without greenhouse gases the average temperature on the Earth would be -18 ^{o}C and the worlds oceans would be covered in ice. Greenhouse effect or global climate change is expressed as grams CO_2 equivalents (Goedkoop, M. 2000).
Greenhouse effect	See Global warming potential.

Gross material consumption	Total material use (kg) per unit that is consumed in order to produce a material type e.g. for use in packaging.
LCA	Life-Cycle Assessment.
Material recycling	Reprocessing of a material (plastic), without changing the chemical structure of the material, to the same type of raw material it was originally (= mechanical recycling).
Material recycling rate	Proportion of plastic packaging that is recycled in relation to the potential plastic packaging.
Nett material consumption	Gross material consumption minus the weight proportion that is assumed to be material recycled after use.
Non-refillable - recyclable bottles	Bottles used in a recycling system. These bottles are used as drink packaging once, before they are sent to material recycling and used as the raw material for new products.
Norsk Resirk AS	Coordinator of the deposit/collection system for non-refillable bottles. Owned by organisations that are involved with drinks production and retail.
Nutrient enrichment	See Eutrophication.
Photochemical ozone creation potential (POCP)	Ozone in the upper layers of the atmosphere protects the Earth from dangerous rays from the sun. Ozone at ground level is, however, dangerous for both humans and nature where concentrations become too great. High ozone levels can lead to health problems, reduced production levels for farms and forestry and material damage. The formation of photochemical oxidant smog is the result of complex reactions between nitrogen oxides and volatile organic compounds (VOCs) in the presence of ultraviolet radiation (present in sunlight) which leads to the formation of ground level ozone. This is a problem in Norway, where the main sources of pollutants contributing to POCP are long-distance air emissions transported on air currents to Norway from other European countries. Emissions in Norway also contribute to the creation of ground-level ozone. Photochemical ozone creation potentials (POCP) of volatile organic compounds (VOCs) are defined as the ratio between the change in ozone concentration caused by a change in the emission of a particular VOC and the change in ozone concentration due to a change in the emission of ethene (i.e. in ethene equivalents, from Goedkoop, M. 2000).
Refillable bottles	Bottles that are used in a refillable bottle system. These are used as drink packaging several times, being washed each time before re-filling.

Retail packaging	Retail Packaging is also known as secondary packaging. This is packaging (often outside consumer packaging) that is required for shop sales. Examples relevant for this study are plastic drinks cases, plastic wrapping and corrugated cardboard trays.
Smog	See Photochemical ozone creation potential (POCP).
Trip rate	The average number of times a refillable bottle is used as drink packaging. This is dependent on the collection rate from the consumer returning the bottles to the shop and the technical rejection rate at the drink producers (where these bottles are washed and refilled).

1 Summary

The debate surrounding which system is the most environmentally effective for drink packaging has appeared in the media at regular intervals. As a result of this, STØ developed a project proposal for Norsk Resirk AS in order to analyse the environmental efficiency for the use of non-refillable-recyclable PET bottles compared with refillable PET bottles used as drink packaging in Norway.

The project assesses environmental aspects associated with the two systems under the present conditions for refillable bottles regarding sales volume, bottle size etc. A large scale change from today's system with refillable bottles to a similar system for non-refillable bottles can lead to structural changes in the drink industry, increased import etc. in addition to present conditions. The authors would like to emphasise that changes in conditions of this nature are not included in the analyses performed.

The aim of this project is to perform an environmental comparison of today's system for refillable PET bottles and a similar system based on non-refillable-recyclable PET bottles. Environmental assessments of the two systems are carried out for equivalent conditions under present constraints.

The study is carried out using life-cycle assessments (LCA) based on the ISO standards 14040-43.

A reference group has been established for this project. This reference group has participated actively in collection and quality assurance of the data used. The referance group has consisted of stakeholders from the whole value chain for drink systems, from bottle producers to recycling plants.

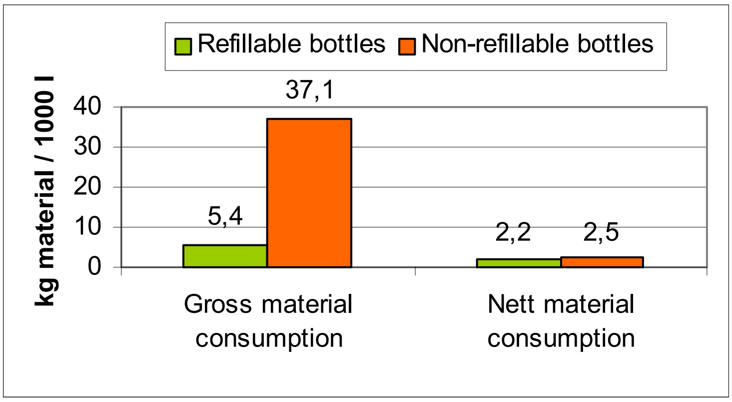
The environmental assessments are calculated in relation to the following functional unit: *Production and transport of packaging, and waste management of used packaging (bottles and retail packaging), that is required for distribution of 1000 l of drinks to the consumer in Norway.*

Important conditions for the main analysis:

- 1000 l of drinks are distributed 70% in 1.5 litre bottles and 30% in 0.5 litre bottles (volume basis).
- The collection rate from the consumer is the same in both systems (97% as for today's system for refillable bottles).
- The weight of a non-refillable-recyclable bottle is about half that of a refillable bottle (of the same volume).
- Trip rates for refillable bottles are 12,75 and 16,5 for 0.5 litre and 1.5 litre bottles respectively.
- The material that is recycled is used for production of new packaging (which is assumed to be partly recycled after use), strapping and fleece, and replaces PET granulate (75% virgin and 25% recycled) and recycled steel.

Results from the main analysis

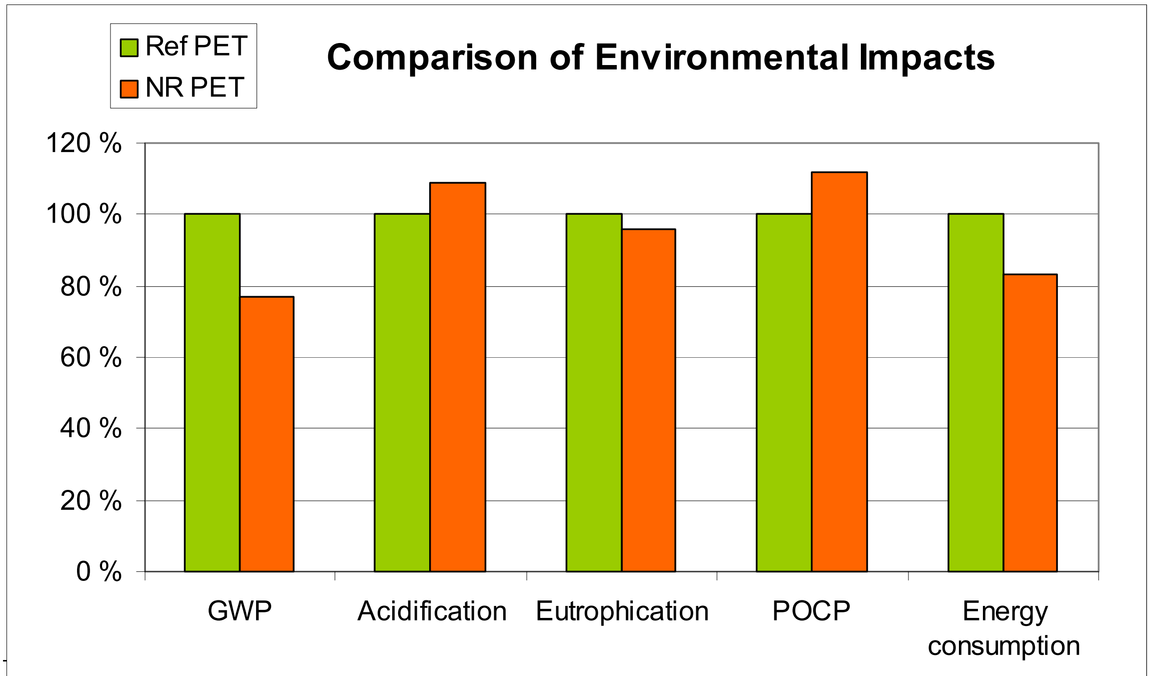
Gross and nett material consumption for refillable and non-refillable-recyclable bottles is shown below.



Gross material consumption is 5.4 kg and 37.1 kg per 1000 litre drinks for refillable and non-refillable bottles respectively. The reason for this large difference between the two systems is that the bottles in the system using non-refillable-recyclable bottles, are used only once, before they are sent to recycling, while the refillable bottles are used many times (trip).

Nett material consumption is 2.2 kg and 2.5 kg per 1000 litre drinks for refillable and non-refillable bottles respectively. The high collection and recycling rate of non-refillable-recyclable bottles is the reason for the large change from gross to nett material consumption for non-refillable-recyclable bottles.

The figure below shows the summary of the environmental impact categories assessed for refillable and non-refillable bottles. The system with refillable bottles is used as the reference system and is shown as 100% for all of the environmental impact categories, and the differences between the systems are presented as percent pints in relation to the reference system (refillable bottles).



The results show that the ranking between the systems with refillable and non-refillable-recyclable bottles varies depending on which environmental impact categories are assessed.

- The system with non-refillable-recylable bottles has results for the environmental impact categories greenhouse effect, eutrophication and energy consumption that are 23% points, 4% points and 17% points <u>better</u> respectively than the system with refillable bottles.
- For the environmental impact categories acidification and photochemical ozone creation potential (smog) the system with non-refillable-recyclable bottles has 9% points and 12% points <u>worse</u> performance respectively than the system with refillable bottles.

The differences between the systems are all within the general uncertainty level for life-cycle assessments of +/- 30% (Hanssen et al., 1996).

Sensitivity Analyses

Sensitivity analyses have been carried out for the parameters that are assumed to be the most important and most sensitive parameters, shown below:

Non-refillable-recyclable bottles	Production of bottles: - Proportion regranulate in bottles - Blowing at the bottle producer contra blowing in-house
	Recycling facility located in Norway
	Introduction of 2 litre bottles for 35% of the total production volume
	Reduced collection rate
Refillable bottles	Trip rate

Conclusions

Based on the results from the main analysis and the sensitivity analyses, the following conclusions can be drawn:

- With the present conditions in the main analysis and based upon general assumptions about the uncertainty level in life-cycle assessments (about +/-30%), the two systems can be described as equivalent for both environmental and resource aspects.
- The sensitivity analyses show at the system with non-refillable bottles will have significantly (>30%) <u>lower</u> environmental impacts than refillable bottles if:
  - Non-refillable-recyclable bottles were produced with at least 35% recycled material (greenhouse effect, acidification and energy consumption).
  - Recycling occurred in Norway (greenhouse effect).

- The sensitivity analyses show that the system with non-refillable bottles will have significantly (>30%) <u>greater</u> environmental impacts than refillable bottles if:

  - Non-refillable-recyclable bottles were solely produced from virgin PET-material (greenhouse effect, acidification and energy consumption).
  - Blowing of non-refillable-recyclable bottles occurred at the bottle producers (all categories).
  - The collection rate for non-refillable-recyclable bottles was lower than 80% (greenhouse effect, acidification and energy consumption).

- The sensitivity analyses show that the following changes in assumptions do not lead to differences between the systems that are greater than the uncertainty level of 30%:
  - Introduction of 2 litre bottles for 35% of the production volume in the system with non-refillable-recyclable bottles
  - Changes in trip rate for the refillable bottles.

2 Background for the study

The debate surrounding which system for drink packaging that is the most environmentally effective comes up in the media at regular intervals, and there is great uncertainty surrounding the environmental aspects associated with the different systems. Documentation of the environmental and resource aspects associated with the different systems for drink packaging has therefore been needed.

Based on this, the Norwegian independent research foundation, STØ, developed a project proposal for Norsk Resirk AS to analyse the environmental efficiency of the use of non-refillable-recyclable PET bottles compared with refillable PET bottles used as drink packaging in Norway.

The authors would like to emphasise that the project only assesses the environmental aspects associated with these differences under today's conditions. A large scale switch from today's system using refillable bottles to a similar system for non-refillable-recyclable bottles can bring about changes in conditions that are different from today's system. These can take the form of structural changes in the drink industry, increased import etc. Changes in conditions of this type are not included in the analyses.

3 Aims

To carry out an environmental comparison of today's system for refillable PET and a system for non-refillable-recyclable PET used as drink packaging for mineral water, squash and water.

The environmental assessments of the two systems were carried out using equivalent assumptions under today's conditions. This means that the environmental assessments for both systems are carried out for the sales volumes/composition of drinks that are sold in today's market using the today's system for refillable bottles.

4 Methodology and organisation

The study is carried out using life-cycle assessments (LCA) based on the ISO-standards 14040-43.

4.1 Short introduction to LCA - methodology

A life-cycle assessment of a product is defined as A systematic survey and assessment of health, environmental and resource effects throughout the whole life cycle of a product, or product system, from 'cradle to grave' (from extraction of raw materials to final disposal). This is based on a *product system*, and assesses environmental and resource aspects of the system in relation to a defined *functional unit*, which is the unit that describes the product's performance in relation to particular user needs.

The life-cycle assessment shall encompass all of the processes and activities that are part of the product system, which as a whole contribute to fulfilling the function or functions that the product system should fulfil.

An example of a life-cycle model for a product system is shown in the figure below.

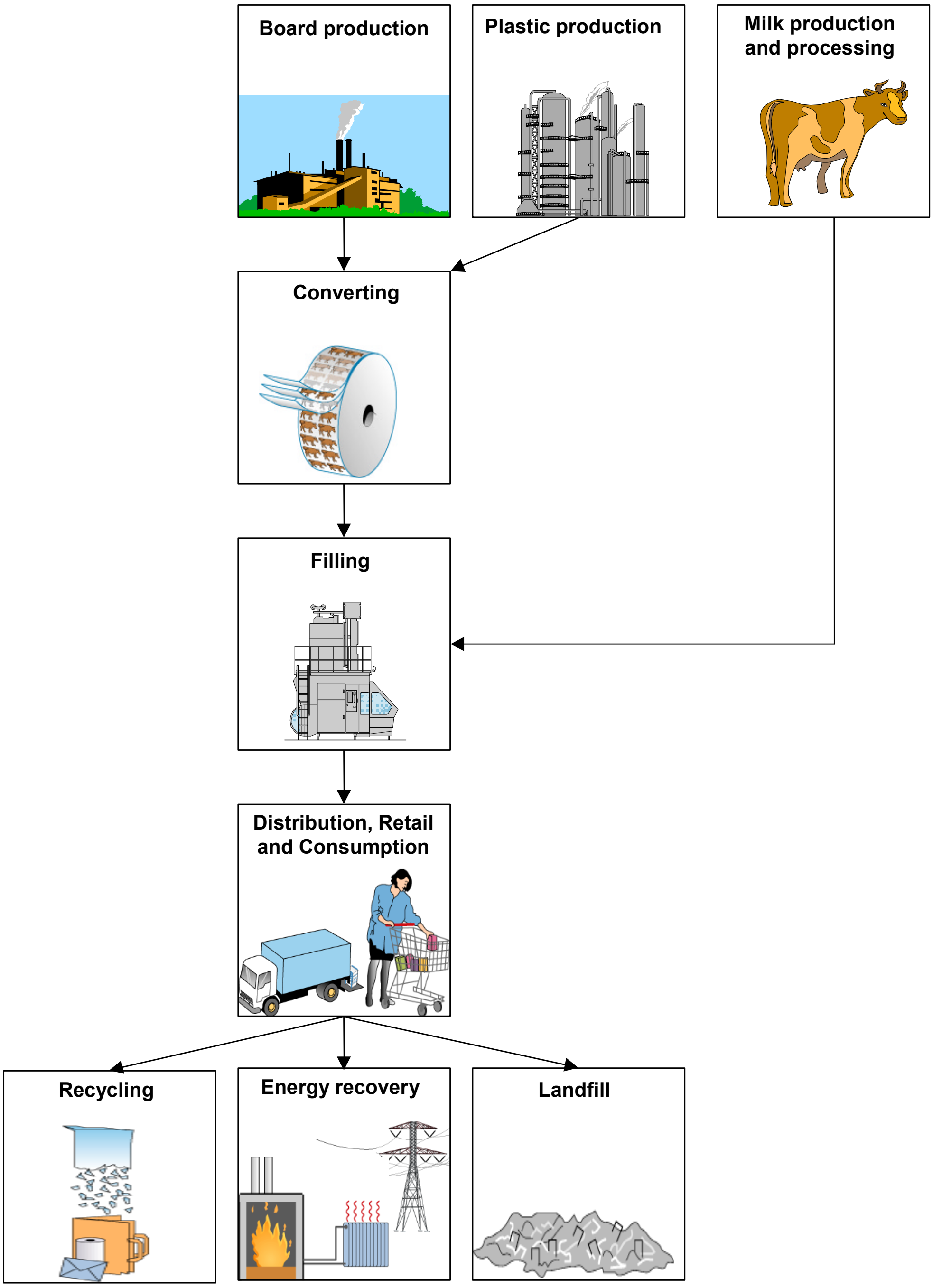


Figure 4.1: *Example of a life-cycle model for a product system for milk (incl. packaging).*

Three central points in a life cycle assessment are:

- one examines the whole technical system required to produce, use and dispose of the product (system analysis), not just the product as such
- one examines the whole material cycle along the product's value chain, not just a single operation, or manufacturing process for a product
- one examines all of the relevant environmental and health affects for the whole system, not just for an individual environmental factor.

This gives a more holistic approach to health, environmental and resource problems than that we have witnessed before. Previously the focus has been upon individual factors, or processes.

The SimaPro 5.1 software has been used in order to carry out the analyses performed.

4.2 Organisation

A reference group has been established during the initial phase of the project. This reference group has actively participated in the collection of data and the quality assurance of the data used. The reference group has consisted of the following stakeholders from different parts of the drink system value-chain:

Rexam Petainer AB	Nisse Nyqvist
Ringnes	Håkon Langen and Halfdan Kverneland Olafssøn
Coca-Cola Drikker	Adrian Stray
Lerum Fabrikker	Jan Audun Larsen
Brænne Mineralvann	Martin Brænne
Telemark Kildevann	Bjørn Bunæs
Stabburet	Bjarne Dahl
Hansa Borg Bryggerier	Alf-Inge Johannessen
Tomra Systems	Bernt Saugen
Hakon Distribution	Roar Getz
BROM/Norsk Returbrett	Morten Sundell and Helge Hasselgård
Expladan Recycling	Steen Birkdal
Grønn hverdag	Kristen Ulstein
Norsk Resirk	Jarle Grytli and Rune Skou
STØ	Ole Jørgen Hanssen and Hanne Lerche Raadal

The reference group's most important task has been to have quality control for the conditions, assumptions, and data used, as well as the results. The reference group has had three meetings during the project period.

5 System description and conditions and assumptions used

Life-cycle assessments have been carried out in order to calculate the environmental impacts arising from the two systems. The environmental impacts are calculated based on the following functional unit:

Functional unit: Production and transport of packaging and waste management of used packaging (bottles and retail packaging) that is necessary in order to distribute 1000 l drinks to the consumer (in Norway).
Conditions for the system: 1000 l drinks distributed 70% in 1.5 litre bottles and 30% in 0.5 litre bottles (volume basis). This means 467 1.5 litre bottles and 600 0.5 litre bottles. The types of drinks are assumed to be 79% mineral water, 14% water and 7% concentrated squash and soft drinks (Hanssen et al., 2003).

Chapter 5.1 gives an overview over the general conditions and data the analyses are based on, while chapters 5.2 and 5.3 give a more detailed descriptions of conditions for the two systems analysed.

5.1 General conditions and data used

In this chapter the general conditions and data the main analyses are based on are described. Sensitivity analyses are carried out in order to test the sensitivity of the results to the conditions and assumptions that are considered most likely to affect the conclusions. These sensitivity analyses are presented in Chapter 7.

5.1.1 Conditions for the main analysis

<u>Choice of environmental parameters</u>
The following five environmental impact categories were chosen, based on general experience from life-cycle assessments of packaging systems (Hanssen et al. 1998):

- Greenhouse effect (GWP, Global Warming Potential)
- Acidification
- Eutrophication
- Photochemical ozone creation potential (smog)
- Consumption of energy

<u>Collection rate = proportion of bottles that are returned to the deposit system</u>
The collection rate of bottles returned to the retailers is assumed to be the same in both systems. The background for this assumption is that the consumers are assumed

to behave in the same way for both systems as long as they have the same general conditions (equivalent deposit system and bottle size). The collection rate of 97% for today's refillable system (Sundell 2003) is therefore used in the analyses.

Weight of bottles and functional unit

Based on the data supplied by the reference group, the following weight of bottles was used:

Type of bottle	**Refillable bottles [g]**	**Non-refillable bottles [g]**
0.5 l	52	26
1.5 l	106	46
Total weight required for packaging of 1000 l drinks (functional unit)	80 700	37 100

Trip rate

Trip rate (the average number of times each bottle is used) is an important assumption for the system with refillable bottles. Non-refillable bottles, on the other hand, have only one trip (the bottles are used only once before recycling).

Refillable bottles are used many times, and the number of trips depends on the collection rate (percent returned to the retailers) and technical rejection rate (at the drink producers).

This can be described by the following equation:

$$\frac{1}{x + y(1 - x)} = \textit{number of trips}$$

where

x = customer wastage (proportion that is not returned to the retailers), and

y = proportion that is technically rejected at the drink producers.

Based on the equation given above, Figure 5.1 shows how the number of trips for 1.5 litre bottles (with a technical rejection rate of 3.4%) varies as a function of customer wastage.

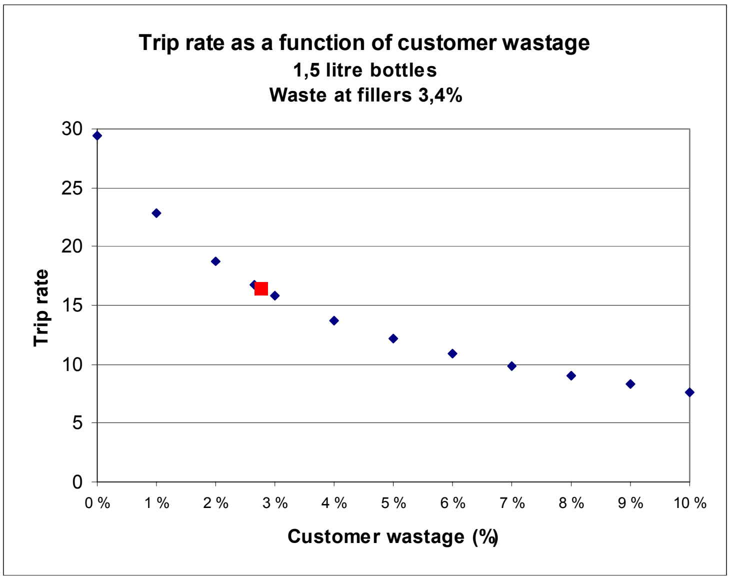


Figure 5.1: *Number of trips as a function of customer losses (the number of trips used in the analysis is shown in red).*

The figure shows that if the customer losses increase to 10% (which means that the collection rate would be reduced to 90%), the number of trips for 1.5 litre bottles would be close to 8. It is likely that the technical rejection rate at the drink producers would reduce if the customer losses increased, as this would mean that more new bottles would be in circulation. If this is the case, the example in Figure 5.1 will give a lower number of trips.

Based on the data gathered from the drink producers in the reference group and BROM, the average number of trips is calculated as 12.75 and 16.5 and technical rejection rate calculated as 5.35% and 3.40% for 0.5 litre and 1.5 litre bottles respectively. Based on these data and the equation given above, the customer losses are calculated as 2.64% and 2.75% for 0.5 and 1.5 litre bottles respectively. This leads to a collection rate of 97.36% (0.5 litre) and 97.25% (1.5 litre) and is thus in good agreement with data from BROM (about 97%, cannot distinguish between different types of bottle and bottle sizes for collection rate, but experience and input from the reference group points to 0.5 litre bottles having a generally lower collection rate than 1.5 litre bottles).

<u>Washing of bottles</u>

Energy consumption for washing refillable bottles before filling and washing non-refillable bottles in the recycling facility is included in the analyses.

Production of detergents and emissions to water from the washing process are however not included in the analyses. This is due to the following:

- *Production and emissions of detergents* are excluded form the analyses as similar types and amounts of detergents are used at the fillers (refillable bottles) and recycling facility (non-refillable-recyclable bottles). The washing process occurs for each trip in both systems, and is detergents used for this are therefore excluded from the analyses.
- *Emissions to water* from the washing process are excluded for two reasons, because the washing processes are assumed to use similar types and amounts of detergents, as well as the assumption that the majority of the aqueous emissions arise from product remains in the bottles. These emissions must be assumed to be similar independent of which bottle type is used, however these emissions will occur in different places. For refillable bottles these emissions will occur at the fillers in relation to the washing process, while for non-refillable-recyclable bottles these emissions will occur when the bottles are baled in the shop. It is assumed that the emissions for both systems are collected in the municipal waste water system and are treated in the municipal wastewater treatment facility.

<u>Return transport (excluding return transport of empty bottles/cases in the system for refillable bottles)</u>

In general it is assumed that 62% of all return transport in the system is utilised, except for cases where the specific stakeholder has provided other, specific data. 62% is given by Statistics Norway (SSB) as the average total transport utilisation in Norway. This assumption is used as the systems use transport companies, which means that the different actors don't have detailed knowledge of the utilisation of return transport journeys. With the specific outward journey transport having a utilisation rate approaching 100%, a return transport efficiency of 62% will give a generally higher total transport efficiency higher than the Norwegian average. This is assumed to be correct for the systems analysed, as there has been great focus on transport efficiency in the distribution systems for drinks packaging in recent years.

Blowing of non-refillable-recyclable bottles
In the main analysis it is assumed that the main quantity of non-refillable-recyclable bottles (98% of the volume that is assessed) are blown in-house at the drink producers. This means that the bottles can be transported as preforms from the bottle producer to the drink producer, which means that this transport is considerably more efficient than the transport of already blown bottles.

Bottle colour
In the system for non-refillable-recyclable bottles, it is assumed that most of the bottles are clear, such as they are in today's system for refillable bottles. This is an important assumption for the use/value of recycled material.

5.1.2 Data used

Energy carrier electricity
A specific energy mix is used for energy carriers in different countries (IEA Statistics, 2002) and data for production of electricity (SimaPro) for different countries related to where the different activities included in the analyses occur.

Data for production of PET granulate
European average data from literature is used for production of PET granulate (APME, 2000). More updated PET production data will be available for European PET production in the first quarter of 2004 (PETCORE).

Data for the recycling process
Specific data for energy consumption in the recycling process for PET is used (from Expladan in Denmark). This is chosen as the case in this project, as non-refillable-recyclable bottles are delivered to this facility at present. In addition, the data from Expladan have been subject to a quality check against data from other PET recycling facilities in Europe: Cleanaway in Germany (Ebel, 2003) and Amcor in Beaune in France (Vincent, 2003).

The material replaced by recycling PET bottles
It is assumed that 85% of recycled material is used for production of new packaging, or fibre products. This material is assumed to replace a mix of 75% virgin PET and 25% recycled PET, independent of whether bottles are originally produced with a certain proportion of recycled PET. The 75/25 mix reflects the average mix of virgin and recycled PET in the total market for PET in Europe in 2002 (Petcore, 2003). Further, it is assumed that about 30% of the proportion of material that is assumed to replace virgin PET (75%), is used for production of products that are also recycled. With collection and recycling, the initial virgin material can replace virgin PET many times (but to a progressively lower degree, as a proportion also replaces recycled PET and a proportion will be used for products that are not recycled in every cycle). Using an arithmetic progression calculation, this will be equivalent to replacing virgin PET 85% (Nyland et al., 2003).

The remaining amount (15%) is assumed to be used for the production of strapping and thus is assumed to replace recycled steel (Birkdal, 2003).

Collection and comparison of data

All of the different stakeholders in the reference group have made a significant contribution to data gathering for the project. In order to systematise and group data collected, the following cases have been constructed for each packaging system, based on the type of distribution at the drink producers:

- One based on the drink producers that currently have their own distribution (Coca Cola and Ringnes), and
- One based on drink producers that currently use retailer distribution (Lerum Fabrikker, Telemark Kildevann and Stabburet).

Presentation of the results is done showing the two cases combined in a common system, based on a weighted average in relation to production volume (86% with own distribution and 14% with retailer distribution).

5.2 System for refillable PET bottles

Figure 5.2 shows the flowchart for refillable PET bottles the analyses are based on.

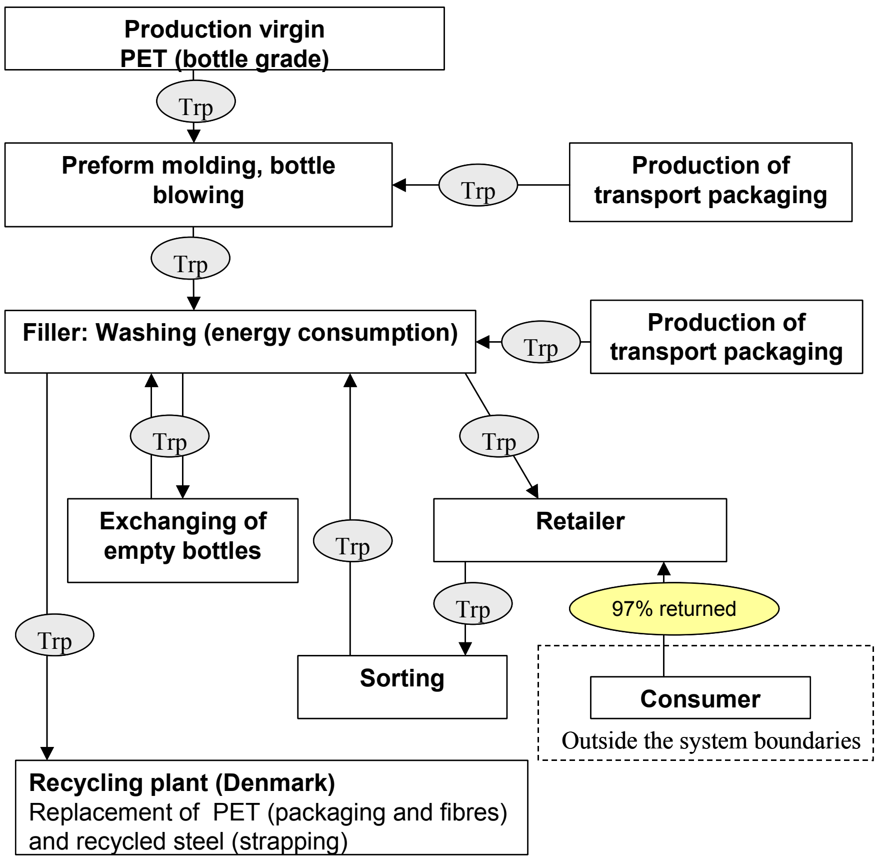


Figure 5.2: *Flowchart for the life-cycle model for refillable bottles.*

It is assumed that refillable bottles are produced from virgin PET (Nyqvist, 2003). The reason for this is the quality requirements for the material for refillable bottles, which amongst other things, means that regranulate from non-refillable-recyclable bottles cannot be used as raw material for refillable bottles.

Specific data and conditions documented for the system for refillable bottles are the property of Norsk Resirk, in the form of confidential appendices.

5.3 System for non-refillable PET bottles

Figure 5.3 shows the flowchart for non-refillable-recyclable PET bottles the analyses are based on.

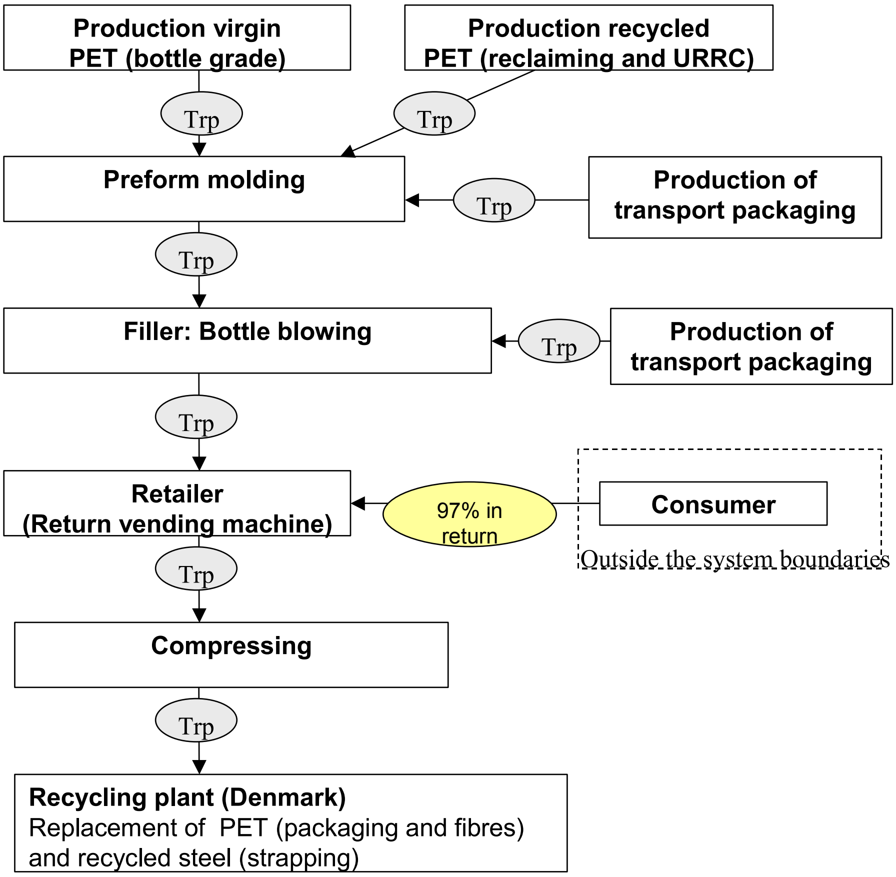


Figure 5.3: *Flowchart for the life-cycle model for non-refillable-recyclable bottles.*

It is assumed that non-refillable-recyclable bottles can be produced from granulate that is partly regranulate and partly virgin granulate (Nyqvist, 2003). In the main analysis it is assumed that all bottles that are not used for packaging water[1] (86% in total), are produced with 25% regranulate. This means a regranulate share of 22% on average per 1000 l drink (functional unit).

Specific data and conditions documented for the system for non-refillable-recyclable bottles are the property of Norsk Resirk, in the form of confidential appendices.

[1] Note: it is possible to use recyclable material for water (Recycled Pet viz. Benelux, Germany, Sweden and Switzerland).

6 Results environmental assessments

The following environmental impact categories were analysed:
- Greenhouse effect (GWP, Global Warming Potential)
- Acidification
- Eutrophication (nutrient enrichment)
- Photochemical ozone creation potential (smog)
- Energy consumption

Table 6.1 under shows examples of which emissions contribute to the different below shows examples of different emissions that contribute to the environmental effects and the potential environmental effects these can give.

Environmental impact category	**Example of emissions**	**Potential environmental effects**
Global warming potential (global climate change/ GWP)	CO_2 N_2O CH_4 CF_4/C_2F_6	Temperature increase in the lower part of the atmosphere that can give rise to climate changes, something that can, in turn, lead to serious consequences for Earth, in the form of a changed/more extreme climate, increased desertification, raised sea levels due to glaciers melting, etc.
Acidification potential	SO_2 HCl NO_x	Fish death, death of forests, corrosion damage, damage to buildings, the release of heavy metals with effects on animals, vegetation and health.
Eutrophication (nutrient enrichment)	Tot N, vann Tot P, vann NO_x	Increased algae growth as a result of an increase in nutrients, which can lead to lack of oxygen and therefore local overgrowth effects in lakes and seawater
Photochemical ozone creation potential (smog) (POCP)	VOC CO NO_x CH_4	Acute toxic effect, negative effect on photosynthesis.
Total energy consumption (resource consumption)	No emissions, but consumption of energy resources in the form of potential energy, solar, wind, tidal and fossil energy.	No direct effects, but changes in the consumption of the different energy carriers can give changes in the other environmental effect categories.

Table 6.1: *Relationship between the relevant environmental impact categories, examples of relevant emissions and potential environmental effects.*

6.1 Material consumption for the systems

Gross and nett material consumption for refillable and non-refillable-recyclable bottles is shown in Figure 6.1.

Gross material consumption is calculated as total material consumption (kg) for packaging (bottles) that is used to package 1000 l drinks (excluding retail packaging).

For refillable bottles the total material consumption for production of bottles was divided by the number of times the bottles were used for drinks (trips).

Nett material consumption is calculated by subtracting the proportion that is material recycled from the gross material consumption.

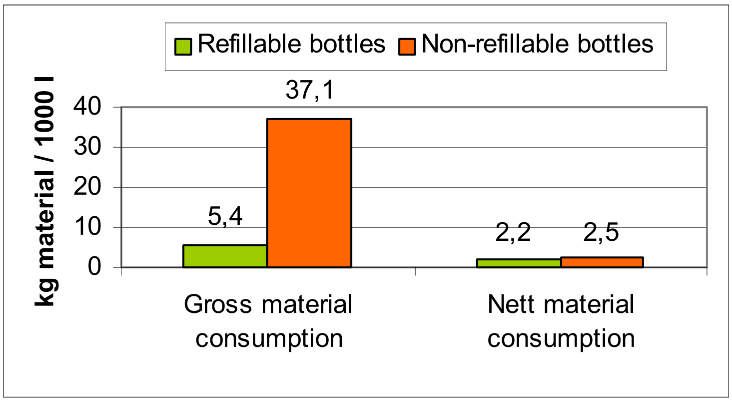


Figure 6.1: *Gross and nett material consumption for non-refillable-recyclable and refillable bottles.*

The figure shows that refillable bottles clearly have the lowest gross material consumption with 5.4 kg per 1000 l drinks. Non-refillable-recyclable bottles have a gross material consumption of 37.1 kg, almost 6 times greater than for refillable bottles. The reason for this large difference in gross material consumption for the two systems is that non-refillable-recyclable bottles are used only once, while refillable bottles are used several times (trips). The total material consumption for refillable bottles can therefore be divided by the number of times the bottles are used (trips).

Nett material consumption for the two bottle types is 2.2 kg and 2.5 kg per 1000 litre drinks for refillable and non-refillable bottles respectively. This means that non-refillable-recyclable bottles have a nett material consumption that is 14 % points (or 1,14 times) greater than the nett material consumption for refillable bottles.

The high collection rate is the reason that refillable bottles have a low gross material consumption, as this means that these bottles are used many times. The difference in gross and nett material consumption arises from the fact that rejected bottles from drink producers are sent to recycling.

High collection and high recycling rates for non-refillable-recyclable bottles are the reason for the large change from gross to nett material consumption for non-refillable-recyclable bottles. This is because the proportion that is returned and recycled is subtracted from the gross material consumption.

6.2 Summary of the assessment of environmental impact categories

Figure 6.2 shows a summary of all of the environmental impact categories assessed for refillable and non-refillable bottles.

The system with refillable bottles is used as the reference system and the values for this system set to 100% for all of the environmental impact categories. The differences between the two systems can thus be seen in the form of percent points in relation to the reference system (refillable bottles).

The total impacts are calculated as a weighted average for the results from the cases with own distribution (86%) and retailer distribution (14%). For a more detailed description of this, see Chapter 5.1.2.

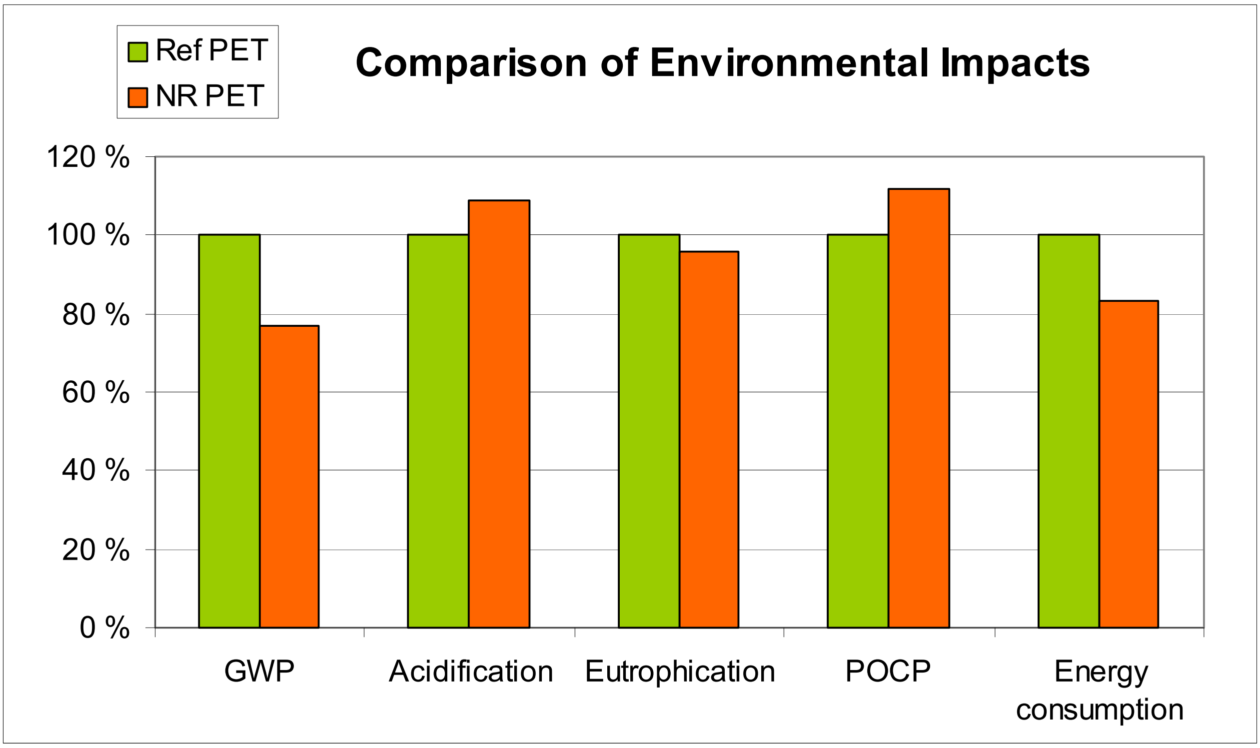


Figure 6.2: *Comparison of the environmental impact categories assessed.*

The results show that the ranking between the systems with refillable and non-refillable bottles varies depending on which environmental impact categories are assessed.

- The system with non-refillable-recyclable bottles has results for the environmental impact categories greenhouse effect, eutrophication and energy consumption that are 23% points, 4% points and 17% points better respectively than the system with refillable bottles.
- For the environmental impact categories acidification and photochemical ozone creation potential (smog) the system with non-refillable-recyclable bottles has 9% points and 12% points worse performance respectively than the system with refillable bottles.

The differences between the systems are all within the general uncertainty level for life-cycle assessments of +/- 30% (Hanssen et al., 1996).

6.2.1 Differences in the systems

This chapter in this report describes the differerences between the systems based on the fact that refillable bottles mainly represent a re-use system, while non-refillable-recyclable bottles represent a recycling system.

Production and recycling of bottles – differences in the systems
For refillable bottles the environmental impacts arising from production of the bottles are distributed over the number of times the bottles are used (trip), this means that fewer bottles are produced per functional unit than for non-refillable-recyclable bottles. This leads to refillable bottles having significantly lower environmental impacts for production of bottles per functional unit (FU) than non-refillable-recyclable bottles (shown by 25.2 contra 112.9 kg CO_2-equivalents per functional unit in Figure 6.3).

The same relationship exists for the benefits from recycling of bottles: in the system with refillable bottles, fewer bottles are produced and thus fewer bottles can be recycled after use (rejected at the drink producers). Therefore the size of the environmental benefit for recycling of bottles is significantly greater for non-refillable-recyclable bottles than for refillable bottles (shown by -8.5 contra –96.1 kg CO_2-equivalents per functional unit in Figure 6.3).

Transport – differences in the systems
The system with refillable bottles requires more transport than the system with non-refillable-recyclable bottles. This is because of the fact that used bottles must be transported all of the way back to the correct drink producer (dependant on bottle type). Transport of whole, empty bottles is a very inefficient transport activity, as the vehicles used are filled with empty bottles and therefore transport a lot of air and little mass.

In the system with non-refillable-recycable bottles, bottles must be transported from the retailers to the recycling facility, but these bottles can be baled immediately after use, which means that the transport efficiency increases significantly (a relatively large tonnage per vehicle).

This means that when comparing the environmental efficiency for systems with refillable and non-refillable-recyclable bottles, it is mainly a comparison of how large the environmental impacts from increased transport in the system with refillable bottles are in relation to the increased impacts with production and recycling (new bottle each trip) of bottles in the system with non-refillable-recyclable bottles. This is presented in more detail in Chapter 6.3.

6.3 Results shown over the life-cycle

In order to show how the different activities (life-cycle stages) contribute to the total environmental impacts for the two systems, the environmental impacts are presented split up into the different life cycle stages for each system. In this chapter the results are presented in this form for each of the environmental impacts assessed.

For the system for refillable bottles, the following life-cycle stages are presented:

Life-cycle stages (activity)	**Description – refillable bottles**
Total	The sum of all of the life-cycle stages (activities) in the system.
Prod./rec. retail packaging.	Production, transport and waste management of the different types of retail packaging in the system
Prod. bottles	Production and transport of bottles and transport packaging to the fillers (divided by the number of trips).
Trp to retailers	Transport of bottles and retail packaging to retailers and management of these in the shop (deposit machine).
Return trp empty bottles	Return transport of empty bottles, cases and trays back to the fillers.
Empty bottles exchange	Transport for exchanging empty bottles between the fillers and delivery of extra trays and cases to retailers.
Sorting	Energy consumption for sorting, including forklift truck driving and heating the areas required.
Washing	Energy consumption for washing of bottles at the fillers.
Recycling	Transport to the recycling facility and recycling of rejected bottles from the fillers, incl. the replacement of materials as a result of this.

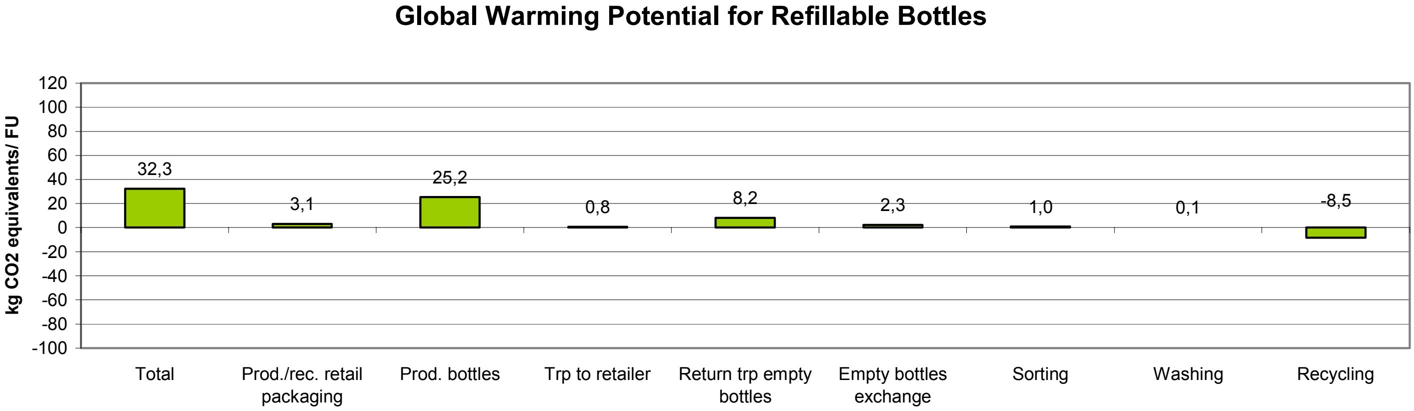
For the system for non-refillable-recyclable bottles, the following life-cycle stages are presented:

Life-cycle stages (activity)	**Description – non-refillable-recyclable bottles**
Total	The sum of all of the life-cycle stages (activities) in the system.
Prod./rec. retail packaging.	Production, transport and waste management of the different types of retail packaging in the system
Prod. Bottles	Production and transport of bottles and transport packaging to the fillers
Trp to retailer	Transport of bottles and transport packaging to retailers and management of these in the shop (deposit machine).
Return trp to fillers	Non-used return transport (empty vehicles returning to the fillers, 38% = Norwegian average)
Trp to recycling	Transport of bottles from retailers to recycling facility, incl. baling in Resirk's depots.
Recycling	Recycling of bottles, incl. the replacement of materials as a result of this.

The authors would like to emphasise that the results that are presented in chapters 6.3.1 to 6.3.5 are valid for the alternative with own distribution (86% of the volume, see the more detailed description in Chapter 5.1.2). This means that there is some discrepancy between the total results shown in Figure 6.2 and figures 6.3-6.6. As the distribution of environmental impacts over the life-cycle will show the same trend independent of the distribution system, this will not interfere with the interpretation of the results in the following chapters.

6.3.1 Greenhouse effect (GWP)

Figure 6.3 shows the contributions to the greenhouse effect (GWP) potential per functional unit (FU) for the two systems, shown for the alternative with own distribution.



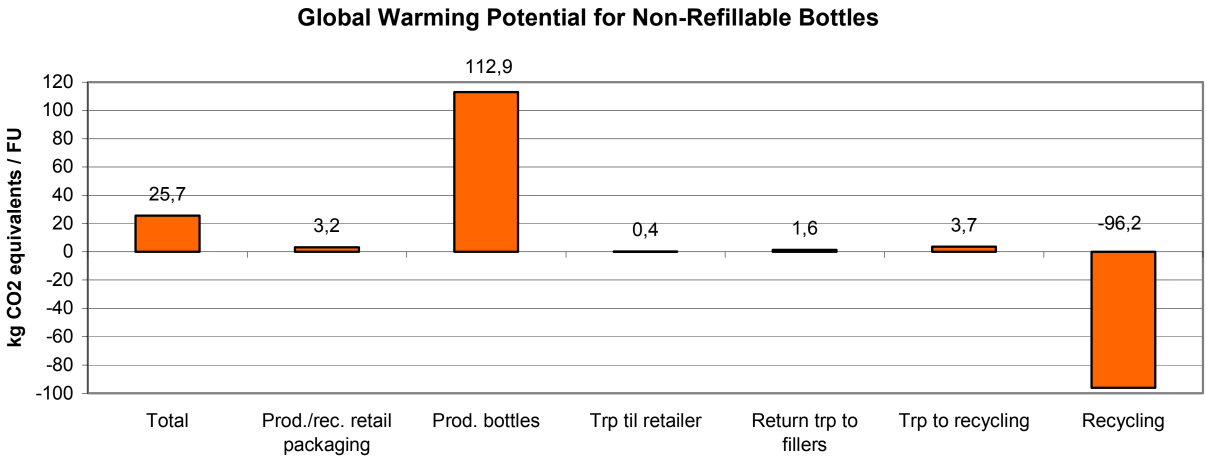


Figure 6.3: *Contributions to greenhouse effect for the two systems.*

The figure shows that non-refillable bottles have the best performance in terms of greenhouse effect/global warming potential. This is mainly due to the fact that the increased impacts from production and recycling (each trip in the system) of non-refillable-recyclable bottles are lower than the environmental impacts from increased transport in the system with refillable bottles.

For refillable bottles, production of bottles gives the largest single contribution in the system, with 78% of the total, while return transport of empty bottles contributes the next largest single contribution (25%). The system has an environmental benefit of -26% of the total, as a result of the recycling of used bottles that are unsuitable for refilling (rejected through the quality control system). This benefit arises because the production of other materials (mainly virgin PET) is replaced by recycled PET.

For non-refillable-recyclable bottles, production of the bottles is the largest single contributor to the emissions of greenhouse gases in the system (440% of the total). The system gains a significant environmental benefit of –375% of the total contribution as a result of recycling used bottles.

6.3.2 Acidification

Figure 6.4 shows the contributions to acidification for the two systems, shown for the alternative with own distribution.

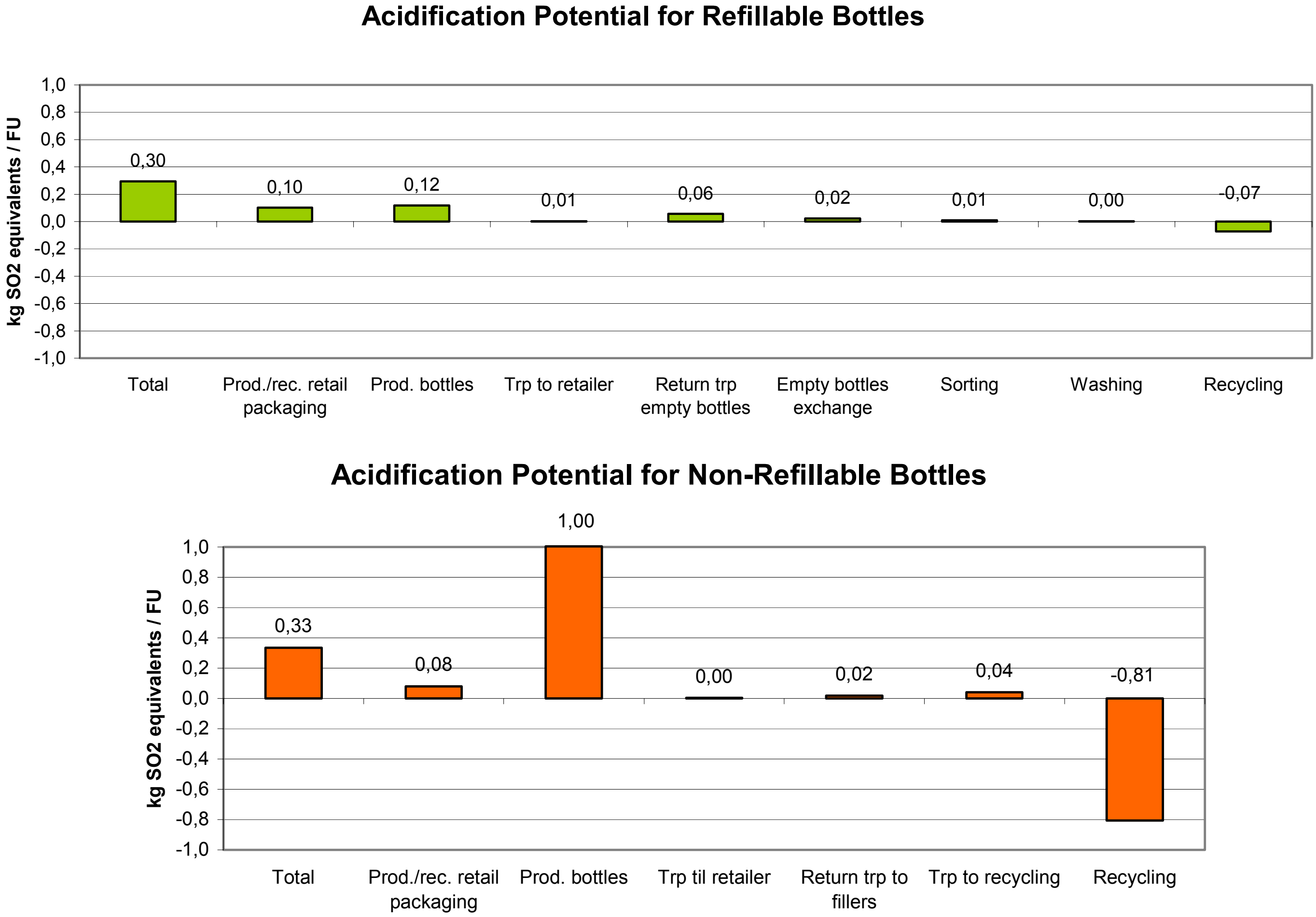


Figure 6.4: *Contributions to acidification for the two systems.*

The figure shows that refillable bottles give the best results when acidification potential is assessed. This is mainly due to the fact that the increased impacts from production and recycling (each trip in the system) of non-refillable-recycable bottles are greater than the environmental impacts from increased transport activities in the system with refillable bottles.

In the system with refillable bottles, production of bottles and production of retail packaging give the largest contributions in the system, with 40% and 35% of the total contributions to acidification respectively. Return transport and empty bottle exchange together contribute 27% of the total. The system gains an environmental benefit from recycling rejected bottles (–24% of the total acidification potential for the system).

In the system with non-refillable-recyclable bottles, production of bottles gives the greatest impact for the system, with 300% of the total, but recycling of bottles gives a similar environmental benefit (–241%).

6.3.3 Eutrophication

Figure 6.5 shows the contributions to eutrophication (nutrient enrichment) for the two systems, shown for the alternative with own distribution.

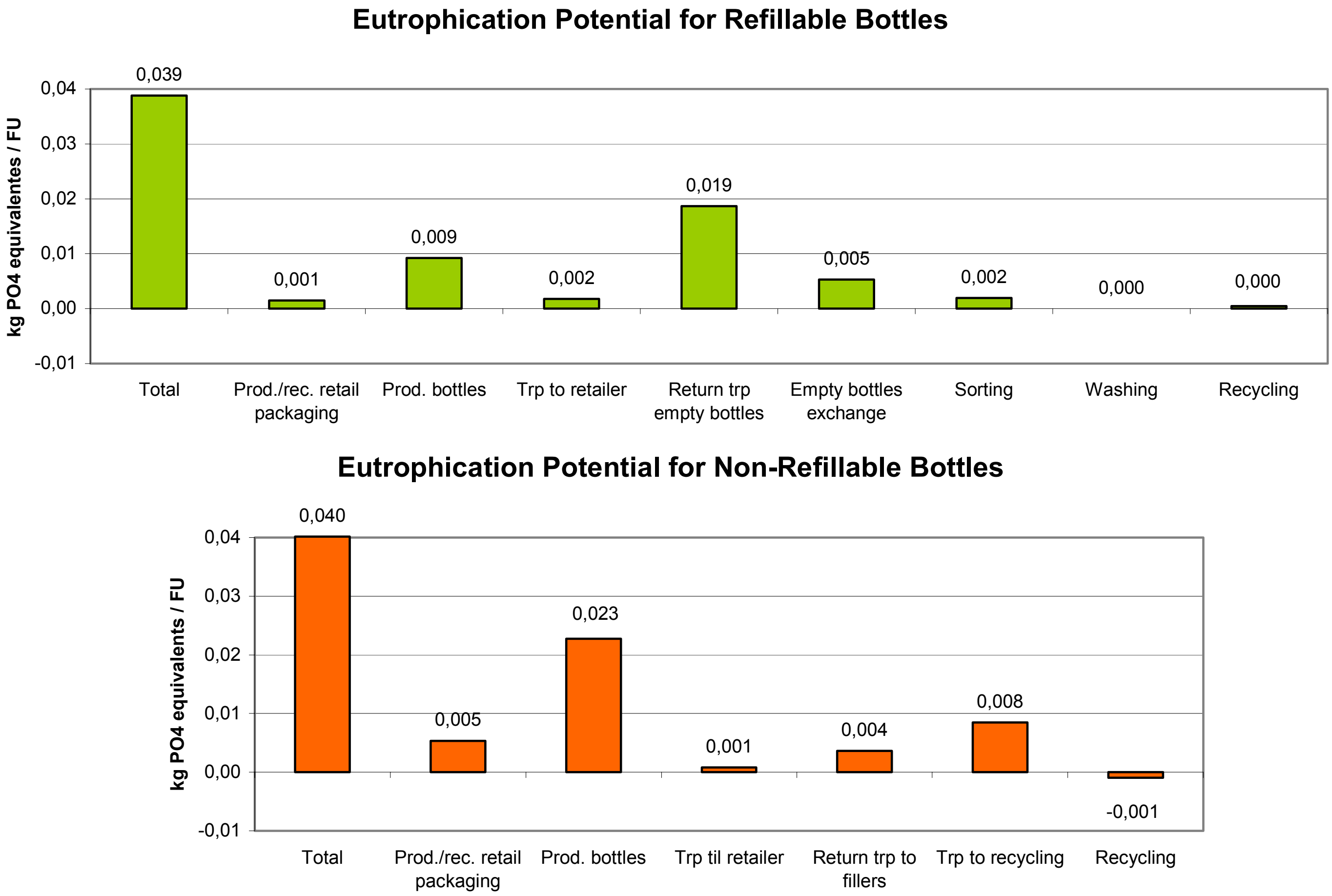


Figure 6.5: *Contributions to eutrophication in the two systems.*

The figure shows that the systems give similar results for the assessment of eutrophication potential. This is as a result of several factors. The increased impacts from production and recycling (each trip in the system) of non-refillable-recyclable bottles are lower than the environmental impacts from increased transport in the system with refillable bottles. In addition to this, increased impacts from production of retail packaging and transport to the recycling facility in the system with non-refillable-recyclable bottles mean that the two systems give similar total results for eutrophication potential.

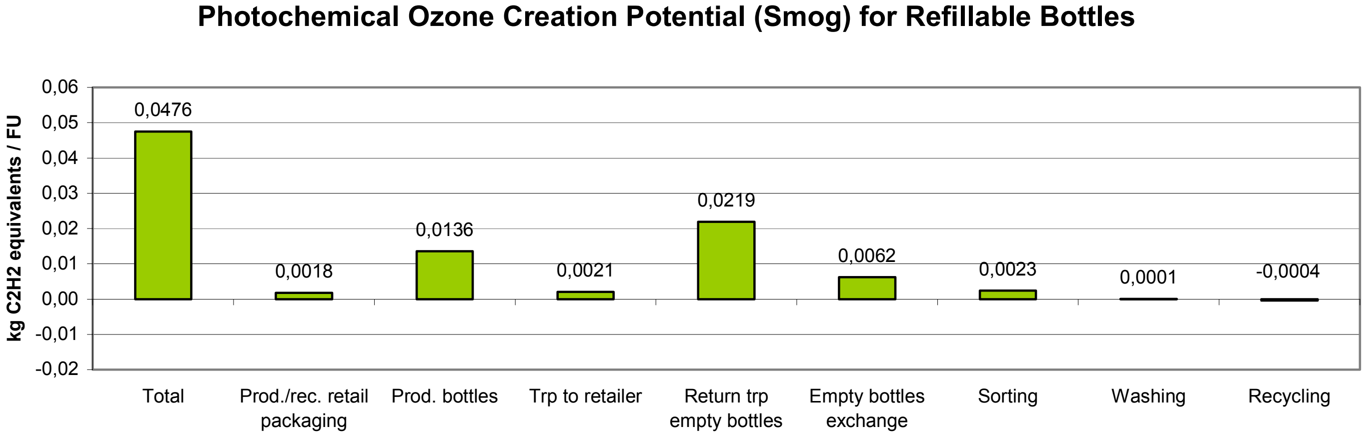
These results are slightly different from those shown in Figure 6.2, where non-refillable-recyclable bottles have a result that is 4% points better than for refillable bottles. The reason for this difference is that the alternative with retailer distribution has greater environmental impacts from transport than the alternative with own distribution for refillable bottles, such that the weighted average is therefore greater for the refillable bottles than that shown in Figure 6.5

In the system with refillable bottles, return transport of empty bottles gives the largest single contribution in the system, with 48% of the total eutrophication potential. Production of bottles has a contribution of 24%, while the exchange of empty bottles gives 14%. Recycling of bottles gives a nett contribution (not an environmental benefit) to eutrophication of 1%. This is because the environmental impacts from transport to the recycling facility and production/use of energy for recycling are greater than the benefits from recycling (replacement of materials) when considering eutrophication.

In the system with non-refillable-recyclable bottles, production of bottles gives the largest single contribution (57%), while transport of baled bottles from retailers to the recycling facility leads to the next largest single contribution for the system (21%).

6.3.4 Photochemical ozone creation potential (smog) (POCP)

Figure 6.5 shows the contribution to photochemical ozone creation potential (smog) (POCP) for the two systems, shown for the alternative with own distribution.



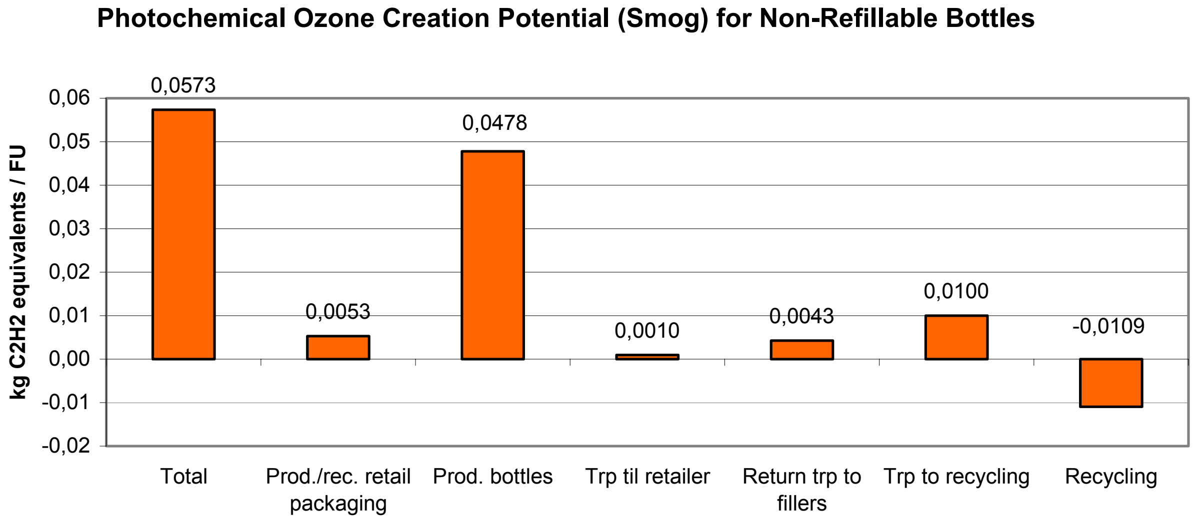


Figure 6.5: *Contributions to photochemical ozone creation potential (smog) for the two systems.*

The figure shows that refillable bottles give the best results when assessing photochemical ozone creation potential (smog). This is mainly because the increased impacts from production and recycling (each trip in the system) of non-refillable-recyclable bottles are greater than the environmental impacts from increased transport in the system using refillable bottles.

In the system for refillable bottles, return transport of empty bottles gives the largest single contribution in the system (46%), while production of bottles contributes with 28 % of the total impacts.

In the system for non-refillable-recyclable bottles, production of bottles gives the largest single contribution (83%), while transport from retailers to the recycling facility accounts for 17% of the total impact. The environmental benefit from recycling bottles gives a negative contribution of –19% of the total impact.

6.3.5 Energy consumption

Figure 6.6 shows energy consumption for the two systems, shown for the alternative with own distribution.

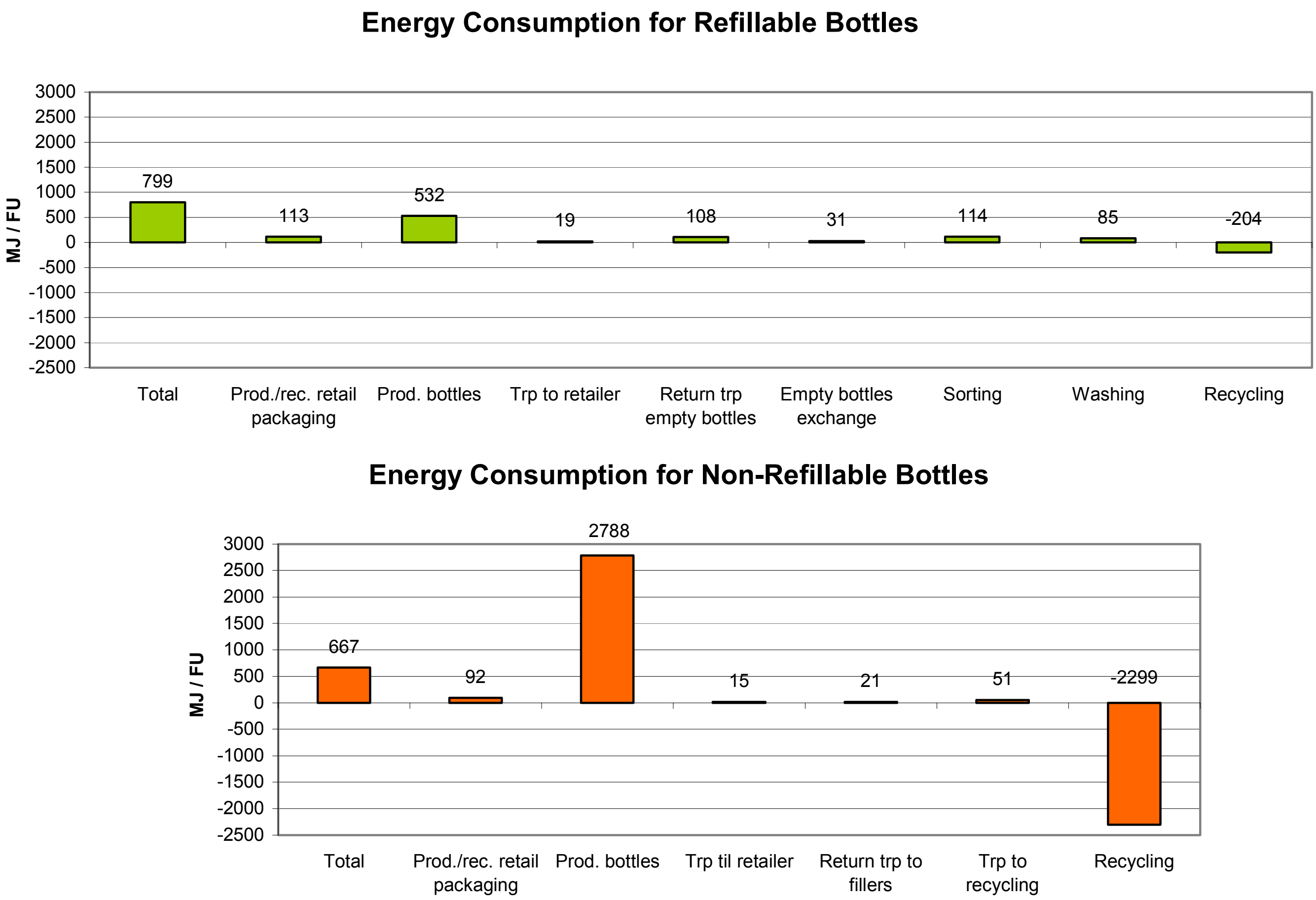


Figure 6.6: *Total energy consumption for the two systems.*

The figure shows that non-refillable-recyclable bottles give the best results when energy consumption is assessed. This is mainly because of the increase in impacts from production and recycling (each trip in the system) of non-refillable-recyclable bottles are less than the environmental impacts from the increased transport in the system with refillable bottles.

In the system with refillable bottles, the production of bottles has the highest energy consumption for the system, with 67% of the total energy consumption. Production /recycling of retail packaging, sorting and return transport of empty bottles both consume about 14% of the total energy consumption.

In the system with non-refillable-recyclable bottles, production of bottles has clearly the largest energy consumption in the system (418%), while production and recycling of retail packaging contribute with 14%. Recycling of bottles gives an energy consumption saving of -344% of the total energy consumption in the system.

6.4 Summary

6.4.1 Results

Gross material consumption for the two bottle types are 5,4 kg and 37,1 kg per 1000 l drinks for refillable and non-refillable-recyclable bottles respectively. The reason for the large difference in gross material consumption for the two systems is that the bottles in the system with non-refillable-recyclable bottles are used only once before they are sent to recycling, while the refillable bottles are used several times (trip).

Nett material consumption for the two bottle types are 2,2 kg and 2,5 kg per 1000 litre drinks for refillable and non-refillable bottles respectively. This means that non-refillable-recyclable bottles have a 14 % (or 1,14 times) greater nett material consumption than refillable bottles. High collection and high recycling rates for non-refillable-recyclable bottles are the reasons for the large differences between gross and nett material consumption for non-refillable-recyclable bottles.

The ranking between the systems with refillable and non-refillable-recyclable bottles varies depending on which environmental impact category is assessed.

- For the environmental impact categories greenhouse effect, eutrophication and energy consumption, the system with non-refillable-recyclable bottles has an environmental performance that is 23%, 4% and 17 % points better than the system with refillable bottles respectively.
- For the environmental impact categories acidification and photochemical ozone creation potential (smog), the system with non-refillable-recyclable bottles has an environmental performance that is 9% and 12% points worse than the system with refillable bottles respectively.

The differences between the two systems are all within the general uncertainty level for life-cycle assessments, +/- 30% (Hanssen et al., 1996).

Conclusion from the main analysis
With the current conditions and assumptions in the main analysis, and taking into account general assumptions about uncertainty levels in life-cycle assessments (about +/-30%), the two systems can be described as having approximately the same environmental and resource impacts.

6.4.2 Important activities in the systems

The most important activities for the two systems, in terms of environmental impacts and environmental benefits throughout the systems' life-cycles, are described here.

Refillable bottles

The most important activities for refillable bottles are as follows (in order of priority):

- Production of bottles (and hence trip rate);
- Return transport of empty bottles, cases and trays and recycling of rejected bottles (benefit from replacing PET and recycled steel);
- Empty bottle exchange and production of retail packaging.

<u>Non-refillable-recyclable bottles</u>

The most important activities for non-refillable-recyclable bottles are as follows (in order of priority):

- Production of bottles;
- Recycling of bottles (benefit from replacing PET and recycled steel);
- Transport to the recycling facility and production of retail packaging.

7 Sensitivity analyses

In order to assess the robustness of the results, sensitivity analyses have been performed for the parameters that were assumed to be the most important and most sensitive. This required testing the following parameters:

For non-refillable-recyclable bottles

- Production of bottles:
  - Proportion of regranulate in bottles;
  - Blowing at the bottle producers instead of in-house (at the drinks producers).
- Recycling facility located in Norway instead of in Denmark.
- Introduction of 2 litre bottles for 35% of the total production volume.
- Reduced collection rate.

For refillable bottles

- Trip rate.

The results from the sensitivity analyses are presented below.

7.1 Non-refillable-recyclable bottles

7.1.1 Proportion of recycled material in non-refillable-recyclable bottles

There is uncertainty associated with what the realistic proportion of recycled material that will be used in production of non-refillable-recyclable bottles will be. In order to assess the importance of the assumption used, analyses of the following two scenarios for the amount of recycled material in bottles were carried out:

- 0% recycled material (only virgin granulate is used)
- 50% recycled material (in bottles that are not used for water[2])

In the analyses it is assumed that the recycled material is only used in bottles that are not used as packaging for water (86%, see Chapter 5.3). This means that the 50% regranulate used in all bottles that are not used as packaging for water, is equivalent to a proportion of 43% per 1000 litre drinks (functional unit).

In Figure 7.1 the results from the sensitivity analyses are presented together with the results from the main analysis (Chapter 6). The two alternatives for the use of recycled material are shown together with the results for non-refillable-recyclable bottles. The interval shown on the graphs in Figure 7.1 represents the difference in results arising from changing the assumption used for how much recycled material is used in the non-refillable-recyclable bottles. The highest level of the interval represents the 0% blend (virgin material only), and the lowest level represents the 50% blend of recycled material.

[2] Note: it is possible to use recyclable material for water (Recycled Pet viz. Benelux, Germany, Sweden and Switzerland).

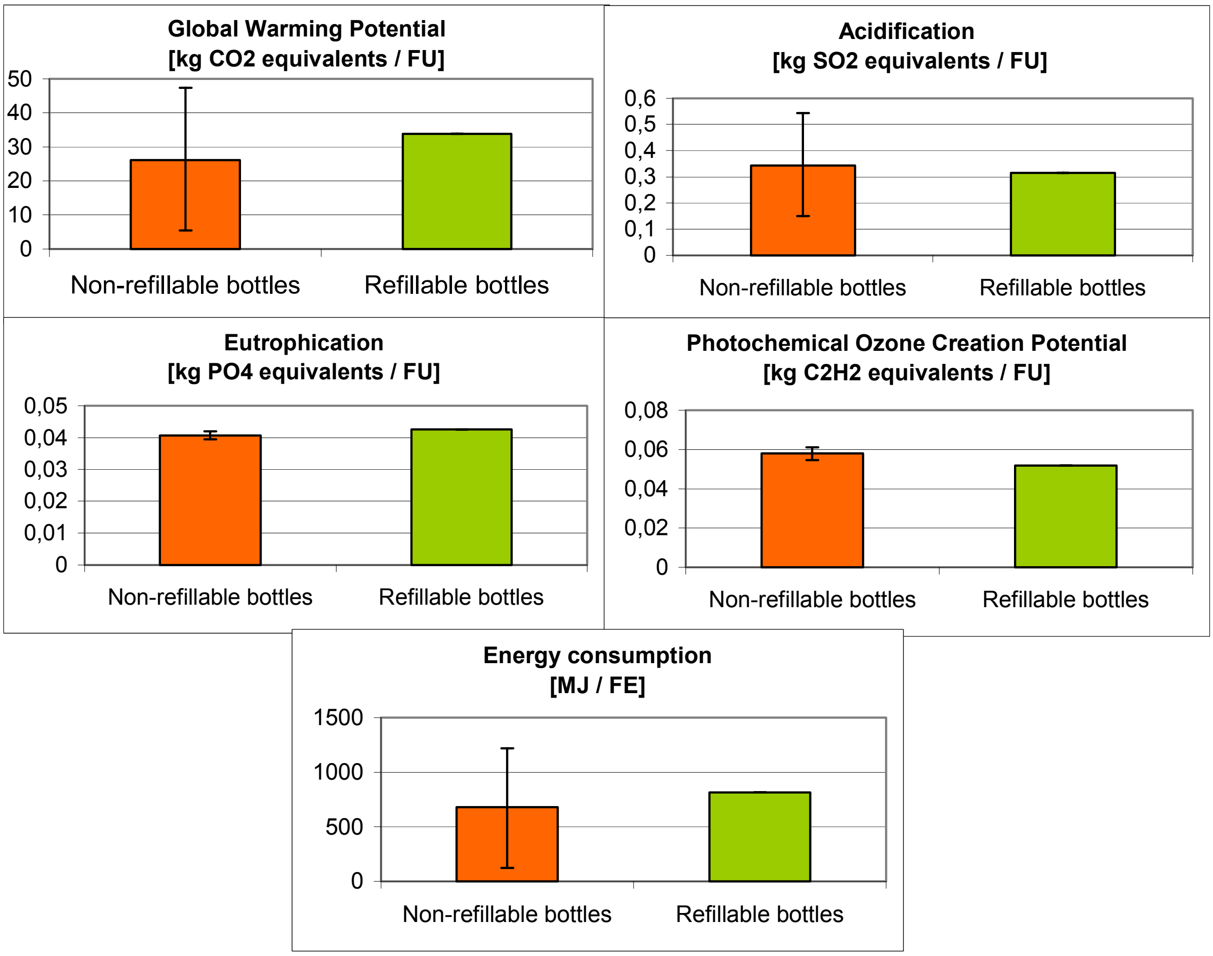


Figure 7.1: *Sensitivity analysis for the proportion of recycled materials in non-refillable*-recyclable *bottles*

Figure 7.1 shows that the proportion of recycled material that is used in production of non-refillable bottles is a very important assumption for environmental impact categories global warming potential (greenhouse effect), acidification and energy consumption. This is, however, of little importance for eutrophication and photochemical ozone creation potential (smog).

The results for non-refillable-recyclable bottles from the main analysis (Chapter 6) are compared with the results from the sensitivity analysis in the table below. The results are given as percent points in relation to the result for refillable bottles.

Environmental impact category	**Results for non-refillable-recyclable bottles shown as % points in relation to refillable bottles as analysed in:**		
	The main analysis (Chapter 6)	**Sensitivity analysis with virgin granulate**	**Sensitivity analysis with 50% recycled material**
Greenhouse effect	-23	+40	-84
Acidification	+9	+72	-53
Energy consumption	-17	+49	-85

Table 7.1:*Sensitivity analysis of the proportion of recycled material in non-refillable-*recyclable *bottles*

Table 7.1 shows that if non-refillable-recyclable bottles are produced with virgin granulate only, the results are affected as follows:

Greenhouse effect:	from being 23% points better to being 40% points worse than refillable bottles
Acidification:	from being 9% points worse to being 72% points worse than refillable bottles
Energy consumption:	from being 14% points better to being 49% points worse than refillable bottles

Production of non-refillable-recyclable bottles with virgin granulate only leads to the system with non-refillable-recyclable bottles having a result that is significantly worse (> 40% points) than that for refillable bottles for the environmental impact categories greenhouse effect, acidification and energy consumption.

If non-refillable-recyclable bottles are produced with 50% recycled material, the results change as follows:

Greenhouse effect:	from being 23% points better to being 84% points better than refillable bottles
Acidification:	from being 9% points worse to being 53% points better than refillable bottles
Energy consumption:	from being 17% points better to being 85% points better than refillable bottles

Production of non-refillable-recyclable bottles with 50% recycled material leads to the system with non-refillable-recyclable bottles having a result that is significantly (>53% points) than refillable bottles for the environmental impact categories greenhouse effect, acidification and energy consumption.

The authors would like to emphasise that the calculations with a proportion of recycled material in bottles as large as 50% is hypothetical, as this assumes a much greater proportion of recycled PET is used in production of new bottles than is the case today.

Summary

The sensitivity analysis concerning the proportion of recycled material in non-refillable-recyclable bottles shows that this is significantly important for the environmental impact categories greenhouse effect, acidification and energy consumption.

For these categories, the system with non-refillable-recyclable bottles will have significantly greater (>30%) environmental impacts than the system with refillable bottles if bottles were produced of virgin PET-material only. Similarly, the environmental impacts will be significantly (>30%) less than the system with refillable bottles if bottles were produced from at least 36% recycled material.

7.1.2 Blowing of bottles at the bottle producers, or the drinks producers.

In the main analysis it is assumed that almost all of the bottles are blown in-house (at the drinks producers). This represents a 'best case' for transport efficiency, as this means that the bottles can be transported as preforms from the bottle producer to the drinks producer. Transport of preforms gives a considerably better transport efficiency than transport of blown bottles.

Some uncertainty is associated with how large a proportion of bottles will be blown in-house (as opposed to at the drinks producers) in the future. Because of this uncertainty, a sensitivity analysis has been carried out to ascertain the environmental effect of blowing all the bottles at the bottle producers, which can be called the 'worst case'.

The results from this sensitivity analysis are shown in Figure 7.2 together with the results from the main analysis (Chapter 6). Results from the analysis of blowing of bottles at the bottle producers are shown together with the results for non-refillable-recyclable bottles (as calculated in the main analysis - in-house blowing) in the form of an interval line.

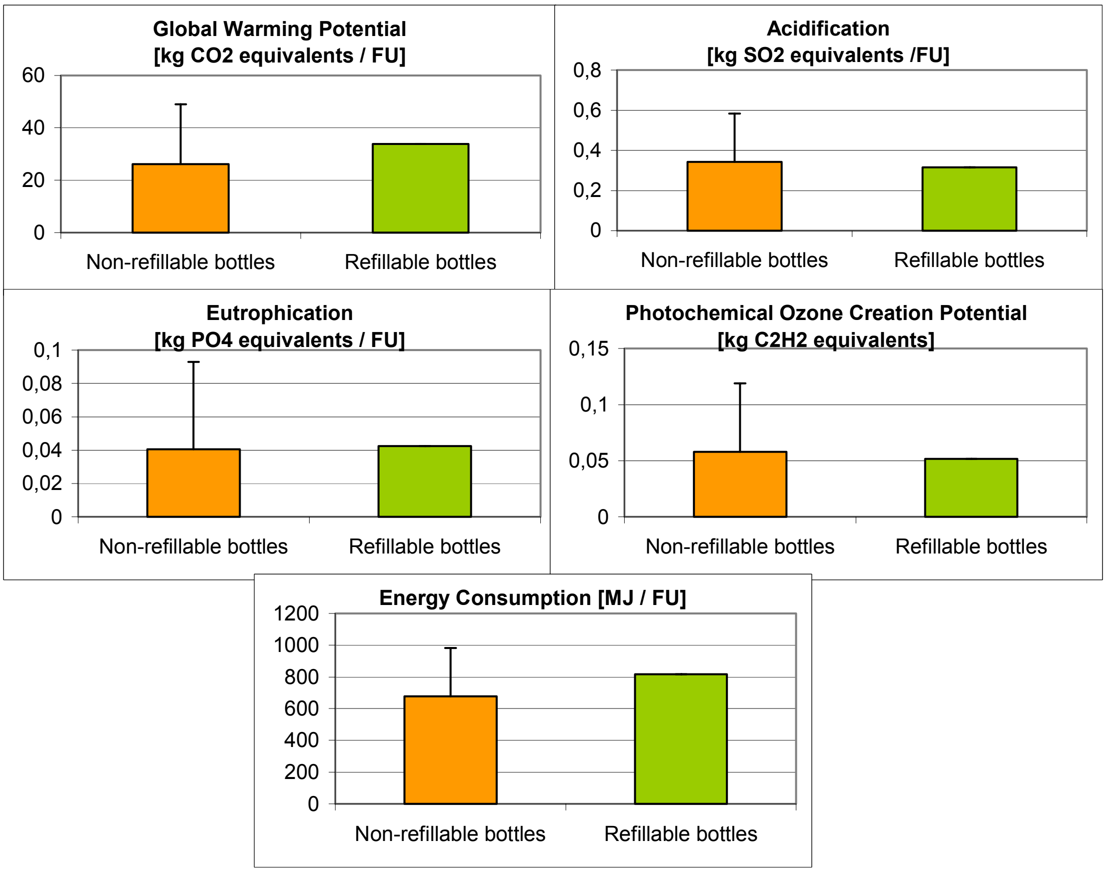


Figure 7.2: *Sensitivity analysis for blowing bottles in-house compared with blowing at the bottle producers.*

The figure shows that in-house blowing has significant importance for all the environmental impact categories assessed. In other words: transport of preforms is so important for bottle transport efficiency that it affects the overall results for the analysis.

The results for non-refillable-recyclable bottles from the main analysis (Chapter 6) are compared with the results from the sensitivity analysis in the table below. The results are given as percent points in relation to the result for refillable bottles.

Environmental impact category	**Results for non-refillable-recyclable bottles shown as % points in relation to refillable bottles as analysed in:**	
	The main analysis (Chapter 6)	**Blowing at the bottle producers**
Greenhouse effect	-23	+45
Acidification	+9	+85
Eutrophication	-4	+118
Photochemical ozone creation potential (smog)	+12	+129
Energy consumption	-17	+23

Table 7.2: *Changes in the results as a result of blowing of bottles at the bottle producers.*

The table shows that if non-refillable-recyclable bottles are blown at the bottle producers, the results are affected as follows:

Greenhouse effect: from being 23% points better to being 45% points worse than refillable bottles.
Acidification: from being 9% points worse to being 85% points worse than refillable bottles
Eutrophication: from being 4% points better to being 118% points worse than refillable bottles
Photochemical ozone creation potential (smog): from being 12% points worse to being 129% points worse than refillable bottles
Energy consumption: from being 17% points better to being 23% points worse than refillable bottles

Summary

If all non-refillable-recyclable bottles were blown at the bottle producers, the transport impacts from the system would be so large that the system with non-refillable bottles would be significantly (>30%) worse than the system for refillable bottles for all of the environmental impact categories assessed except for energy consumption (23% points worse).

7.1.3 Recycling facility located in Norway

Based on information from Resirk, it is possible that a large-scale introduction of non-refillable-recyclable bottles onto the Norwegian market could lead to the establishment of a recycling facility in Norway.

This change would lead to a change of energy mix for electricity that is used in the recycling process (from the Danish to Norwegian energy mix). This will also have implications for the transport involved, but it is assumed that the recycled material must be transported to the European market and will thus have a similar transport distance to today's situation (to Denmark).

The results show that the environmental impact categories greenhouse effect, acidification and energy consumption are affected by this assumption (the other impact categories are not affected to a significant degree).

The results for non-refillable-recyclable bottles from the main analysis (Chapter 6) are compared with the results from the sensitivity analysis in the table below. The results are given as percent points in relation to the result for refillable bottles.

Environmental impact category	**Results for non-refillable-recyclable bottles shown as % points in relation to refillable bottles as analysed in:**	
	The main analysis (Chapter 6)	**Recycling facility in Norway**
Greenhouse effect	-23	-45
Acidification	+9	-6
Energy consumption	-17	-26

Table 7.3: *Changes in the results as a result of the recycling facility being located in Norway.*

Table 7.3 shows that if the recycling facility were located in Norway, the results for the system for non-refillable-recyclable bottles would improve by between 6% points and 22% points in relation to the system with refillable bottles, dependant on which environmental impact category is assessed.

Summary

If the recycling facility was located in Norway, the system with non-refillable-recyclable bottles would be significantly (>30%) better than the system with refillable bottles for greenhouse effect. For the other environmental impact categories, this change will not lead to significant differences between the systems.

7.1.4 Introduction of 2 litre bottles

It is likely that a large-scale introduction of non-refillable-recyclable bottles will lead to an increase in 2 litre bottles for a certain proportion of the production volume (Bunæs, Stray et al.). This scenario is not assessed for refillable bottles, as it is considered unrealistic (reference group). .

The environmental effect of introducing of 2 litre non-refillable-recyclable bottles is assessed based on the assumption that the 2 litre bottles would be used for about 50% of the 1.5l bottle sales volume (equivalent to 35% of the total production volume). This change will mean a reduced packaging consumption per functional unit.

The results for non-refillable-recyclable bottles from the main analysis (Chapter 6) are compared with the results from the sensitivity analysis in the table below. The results are given as percent points in relation to the result for refillable bottles.

Environmental impact category	**Results for non-refillable-recyclable bottles shown as % points in relation to refillable bottles as analysed in:**	
	The main analysis (Chapter 6)	**Introduction of 2 litre bottles**
Greenhouse effect	-23	-26
Acidification	+9	+4
Eutrophication	-4	-9
Photochemical ozone creation potential (smog)	+12	+7
Energy consumption	-17	-21

***Table** 7.4: Changes in the results as a result of the introduction of 2 litre bottles.*

The results show that introduction of 2-litre bottles would lead to an improvement in the system with non-refillable-recyclable bottles of between 3-5% points in relation to the system with refillable bottles. This conclusion is relevant for all of the environmental impact categories assessed.

<u>Summary</u>
Introduction of 2 litre bottles leads to improvements for the system with non-refillable-recyclable bottles, but these improvements are not large enough to be significant (>30%) differences between the systems.

7.1.5 Reduced collection rate

Based on the experience that non-refillable-recyclable bottles can have a lower collection rate than refillable (Ulstein et al.), a sensitivity analysis has been performed in order to find the collection rate where a break-even point (for environmental impacts) is reached for non-refillable and refillable bottles.

Because the results for the different environmental impact categories vary, it is emphasised that the sensitivity analysis gives the greatest weight to the impact categories greenhouse effect and energy consumption, since these categories represent the largest differences between the systems in the main analysis.

The results show that the system with non-refillable-recyclable bottles must have a collection rate that is 80% lower than in the main scenario in order for greenhouse effect, acidification and energy consumption to be significantly (>30%) worse than the system with refillable bottles.

7.2 Refillable bottles

7.2.1 Trip rate

Sensitivity analyses are carried out in order to establish how large a change in trip rate is needed in order to get the same results (environmental impacts) for the two systems.

As shown in Chapter 5.1.1, the trip rate is dependant on the rejection rate at the drink producers and the consumer collection rate. The sensitivity analysis is based on variation of the technical rejection rate at the fillers, as varying the consumer collection rate would mean changing the basic assumption that the consumer collection rate is the same for both systems.

The results from the sensitivity analysis are summarised in the table below.

Environmental impact category	**0.5 litre bottles, trip rate**		**1.5 litre bottles, trip rate**	
	Main analysis	**Scenario**	**Main analysis**	**Scenario**
Greenhouse effect	12,75	25	16,5	32
Acidification		10		14
Eutrophication		21		27
Photochemical ozone creation potential (smog)		9		12
Energy consumption		19		25

Table 7.6: *Changes in trip rate in order to obtain equivalent results for the two systems.*

The results show that for the environmental impact categories greenhouse effect, eutrophication and energy consumption the trip rate for refillable bottles must be 19 or more, which is unrealistic. This means that changes in trip rate alone cannot lead to the two systems giving the same results.

8 Conclusions

Based on the results from the main analysis and the sensitivity analyses, the following conclusions can be drawn:

- With the present conditions in the main analysis and based upon general assumptions about the uncertainty level in life-cycle assessments (about +/-30%), the two systems can be described as equivalent for both environmental and resource aspects.
- The sensitivity analyses show at the system with non-refillable-recyclable bottles will have significantly (>30%) lower environmental impacts than refillable bottles if:
  - Non-refillable-recyclable bottles were produced with at least 35% recycled material (greenhouse effect, acidification and energy consumption).
  - Recycling occurred in Norway (greenhouse effect).

- The sensitivity analyses show that the system with non-refillable-recyclable bottles will have significantly (>30%) greater environmental impacts than refillable bottles if:
  - Non-refillable-recyclable bottles were solely produced from virgin PET-material (greenhouse effect, acidification and energy consumption).
  - Blowing of non-refillable-recyclable bottles occurred at the bottle producers (all categories).
  - The collection rate for non-refillable-recyclable bottles was lower than 80% (greenhouse effect, acidification and energy consumption).

- The sensitivity analyses show that the following changes in assumptions do not lead to differencesbetween the systems that are greater than the uncertainty level of 30%:
  - Introduction of 2 litre bottles for 35% of the production volume in the system with non-refillable-recyclable bottles
  - Changes in trip rate for the refillable bottles.

9 Additional Comments

Water consumption is not included as a resource in the study. Coca-Cola (Stray, 2003) has documentation that shows that the water consumption in a system with non-refillable-recyclable bottles is about 25% less than for a system with refillable bottles.

Possible structural changes as a result of a future large-scale change in from refillable to non-refillable-recyclable bottles are not included in the analyses presented in this report. There is a tendency (independent of the type of system) towards more centralisation, which will lead to increased transport distances in both systems. Based on the results presented in Chapter 6, the environmental effects of the increased transport distances (assuming in-house blowing of non-refillable-recyclable bottles) will affect the system for refillable bottles most. Structural changes in general (possible increased centralisation, increased import etc.) arising from a possible large-scale change to non-refillable bottles can be assessed in future work.

A change to non-refillable-recyclable bottles will facilitate greater potential for variations in design and can have effects on hygiene issues/food security. These aspects are not considered in this study.

There has been some discussion in the reference group about the correct bottle weight. A more detailed assessment of this can be part of further work.

The reference group has also discussed the assumption that refillable bottles are produced with virgin PET only (no regranulate). Because this assumption has been proven to be significant in the system for non-refillable-recyclable bottles, it is suggested that an assessment of this assumption for the refillable bottle system can be performed as further work.

A closed loop system for non-refillable-recyclable bottles. An assessment /optimisation of a more closed system (bottle to bottle) can be of interest for further work.

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