Environmental impact of refillable vs. non-refillable plastic beverage bottles in Norway

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This is the authors' final, accepted and refereed manuscript to the article published in

International Journal of Environment and Sustainable Development,
12(2013)4: 379-395

DOI: http://dx.doi.org/10.1504/IJESD.2013.056343

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Abstract

This research compares the environmental impact, in terms of greenhouse gas emissions, of using refillable polyethylene terephthalate (REF-PET) and non-refillable polyethylene terephthalate (NR-PET) bottles in the Norwegian soft drink and carbonated water market. A Microsoft Excel spread sheet was developed in close cooperation with Coca-Cola, Mack, Telemark Springwater, and three of the main food wholesalers in Norway: NorgesGruppen, Coop, and Rema. While academic writers have criticised such life-cycle analysis as impractical, too time-consuming, expensive, and demanding too much effort, and instead advocated qualitative evaluation methods, this project demonstrates that a data-based approach is fully feasible.

We identify the CO_2 emissions associated with various activities, and find that NR-PET bottles generate 18 per cent less CO_2 emissions than REF-PET bottles. This research provides practical suggestions for achieving environmentally friendly packaging solutions. As a consequence of the study findings, the grocery industry initiated efforts to change legislation, and major Norwegian actors have changed their policies.

Keywords: packaging, environmental account, recycling, reusing, bottles, beverage logistics, non-refillable bottles, refillable bottles

Introduction

Currently, two different bottles are used in the Norwegian soft drink and carbonated water market: refillable polyethylene terephthalate (REF-PET) and non-refillable polyethylene terephthalate (NR-PET) bottles. Traditionally, the choice of packaging has been made on the basis of cost considerations (Linton, Klassen, and Jayaraman, 2007). In Norway, there is a toll on beverage bottles, approximately 0,14 Euros per bottle (Toll- og avgiftsdirektoratet, 2012) but there is no toll on REF-PET bottles (provided that there is a return rate of at least 95 per cent). This focus on costs in the selection of a packaging system can result in sub-optimal solutions from an environmental point of view and reduced competitiveness (Vernuccio, Cozzolino, and Michelini, 2010). In practice, the toll on beverage bottles in Norway means that NR-PET bottles are too expensive, and mostly REF-PET bottles are used.

For beverage containers used in the consumer market, firms can choose between refillable or non-refillable bottles, the latter type with or without refund. While these alternatives can be compared on the basis of costs, the effects on the environment also need to be systematically examined. Indeed, converting sound environmental practices into firm profitability is by no means an easy task (Wu and Dunn, 1994), but there is a growing tendency to take an ethically sound approach to packaging by assuring eco-compatibility (Vernuccio et al., 2010; Business Insights, 2008); both producers and users are concerned with environmental sustainability. At the same time, in the European Union, legislation (The European Council Regulation 94/62/E.C. in 1994) seeks to diminish the negative environmental impacts of packaging, and packaging-related waste, including a recommendation to conduct 'cradle to grave' life-cycle assessment of all packaging materials. A high priority has been placed on the refilling and reuse of containers, recycling and energy conversion, e.g. by introducing the 'polluter pays' principle. Therefore, assessing packaging's effects on the environment is called for, but despite the topic's importance (Vernuccio et al., 2010, p. 340) little is written on the subject.

In an attempt to fill some of this gap, the purpose of this paper is to set up an account of the CO_2 emissions related to refillable and non-refillable plastic bottles. More specifically, we calculate the CO_2 emissions resulting from production, packaging, transport handling, and reuse/recycling of NR-PET and REF-PET bottles in the Norwegian soft drink and carbonated water market. Based on our analysis, the climate impact of packaging decisions can be assessed. This analysis has two components: analysis of emissions related to the production and recycling/washing processes and the analysis of transport-related CO_2 emissions.

Dagligvarehandelens Miljøforum financed the study (Econ Pôyry, 2011). Dagligvarehandelens Miljøforum is a forum within the groceries sector for coordination of common challenges linked to sustainable transport and reduced environmental impact, with a focus on optimisation of the value chain through evaluation of logistics, packaging, and load-bearers (www.etos.no). The forum represents 95 per cent of the Norwegian Grocery industry (the four major players).

The environmental impacts of reusing and recycling bottles

Vernuccio et al. (2010) define eco-compatibility as: *Facilitation of recycling activity; reduction of waste; reduction of harmful materials; reduced use of materials; reduction of the risk of environmental damage; energy savings in the production process; re-use of packaging; use of ecological or certified materials; use of recycled materials.* The key challenge is how to minimise the environmental impact of packaging materials (Prendergast and Pitt, 1996). However, beyond classifying sustainability issues and investigating perceptions among packaging professionals, marketing managers, and end consumers about environmental questions (Bone and Corey, 2000; Prendergast and Pitt, 1996), scarce attention has been devoted to actually assessing the environmental impacts of different packaging systems.

Reusing bottles is an important way to reduce packaging waste. Reusing means returning, cleaning, and refilling bottles. This method is relevant when the costs of returning, washing, and refilling are less than for using new bottles (Vogas, 1995). The alternative is to use recyclable bottles. The recycling of plastic bottles was introduced in the Norwegian market in 1989, while a refund scheme for NR-PET recyclable bottles was introduced in 1999. During this period, both the NR-PET and REF-PET bottles were "light-weighted" as compared to earlier PVC bottles. This led to reduced lifetime and fewer instances of reuse for the REF-PET bottles. Regranulate and biomass have been introduced as raw materials for NR-PET bottles, while REF-PET bottles have not had similar technological developments. One reason for this is that the mixtures including biological material have not satisfied the very strict hygiene requirements for REF-PET bottles.

Greenhouse gas emissions from the two bottle types have been analysed in previous research; Lerche Raadal et al. (2003) conducted a life-cycle analysis of NR-PET and REF-PET bottles but found marginal differences. Eidhammer's (2005) analysis identifies substantially higher CO_2 emissions from both bottle systems compared to our analysis. This is probably due to differences in methodology, assumptions, and limitations. Besides these studies, we found no relevant research reported in the literature. In recent years, use of REF-PET bottles for soft drinks and carbonated water has mostly been a Norwegian phenomenon, which might explain the lack of international studies that compare these bottle types. In Europe, the percentage of returnable packaging is declining (in Greece, this percentage is less than 10 per cent for bottles). However, Coca-Cola has successfully introduced the REF-PET bottles in the Netherlands, Germany, and Switzerland (Mandaraka and Kormentza, 2000).

In previous studies, parameters regarding the transport of extra empty crates to stores have not been included. In recent years, there has also been rapid technological development in the production of NR-PET bottles. Consequently, a new analysis is necessary.

Methodology

An environmental account describes environmental impact in terms of the energy and material consumption, as well as waste and pollution released in the environment (air and water) during all or part of the product life cycle (PLC). If the entire PLC is covered ('cradle to grave' perspective), the whole process from extraction of raw materials, production, and distribution to use, reuse, maintenance, materials, and energy formulas is covered along with final disposal and all transportation involved.

By limiting ourselves to studying the environmental impact in terms of CO_2 emission, this study differs methodologically from the ISO standard for life-cycle analysis (LCA). The main reason is that it is assumed that other environmental effects in Norway are marginal. In addition, both types of bottles are made from the same material (PET). Differences in emissions from production can therefore primarily be attributed to the volume of plastics being produced and the raw material used in PET production.

We analysed two types of data in order to evaluate the environmental impact of REF-PET and NR-PET bottles:

(1) Empirical. Two members of the research team conducted numerous interviews with various company representatives in Norway and Sweden from Coca-Cola, Mack, Grans, and Telemark Springwater. In total, these four suppliers represent approximately 50 per cent market share of the Norwegian market. They further interviewed representatives from the four dominant wholesalers: Coop, ICA, NorgesGruppen, and Rema. As for recycling, interviews were conducted with key informants from Norsk Resirk, Rexam, and Cleanaway. As part of

this process, mapping was carried out in order to understand the physical flows associated with the supply chain. Data collection started with interviewing key informants from the producers and wholesalers. The interviews were conducted person-to-person for those situated in the Oslo region and by telephone for those situated elsewhere in Norway or abroad. During these interviews, further key informants from the same organisation and others (producers and recyclers of bottles) were identified. In total, 15 key informants participated in the study. The interviews were followed up by e-mails that summarised the interviews and, in some cases, asked for further information. The data we collected were primarily quantitative facts and figures illustrating the production and recycling process, and the transport involved throughout the life cycle. Later, these were supplemented by qualitative data according to need.

(2) Analytical. An important task was to validate the environmental account model apt for comparing the environmental effects of these two packaging alternatives. In this process, data from the companies on the details of various aspects of physical flows in the supply chain were used. Using this data, it was possible to quantify various assumptions and inputs to the environmental account model, such as return rates, transportation distances, and transported volumes. Through the fieldwork, references were identified to a number of documents that provide insights into the nature of environmental impact of productive processes and materials. Using this information, several assumptions were made (e.g. with regard to energy consumption and CO_2 emissions).

By analysing different data sources using a triangulation approach (Mangan et al., 2004), it was possible to ensure the robustness of the research. To study only the Norwegian market as a single case study is suitable because Norway, in this respect, represents a unique case (REF-PET bottles do not have the same predominant position in other countries), and access to other, similar markets is generally not possible (Ellram, 1996).

PET bottles for soft drinks and carbonated water sold in grocery stores and in kiosks and petrol stations were considered in this study. Accordingly, bottles sold in hotels, restaurants, and cafés, including beer, were not included. It is assumed that the market distribution remains unchanged by a transition to NR-PET bottles. Furthermore, in-bound transportation of materials and other input to production of bottles was left out, since most of this travels by ships and has low emissions. In addition, the origin of such materials and inputs is often unknown (calculations of energy consumption cannot be made). In 2009, the Norwegian market for soft drinks and carbonated water was 499 million litres. Still water is excluded as it is always distributed in NR-PET bottles for quality reasons.

There are several different types of beverage bottles and cans, but we have concentrated on the most common: 0.5 L and 1.5 L PET bottles for soft drinks and carbonated water. Other sizes, cans, and glass bottles are not included. Overall, we have excluded an estimated 20 million litres (about 4 per cent) of the total market for soft drinks and carbonated water. In the analysis, we operate with a standard unit of 1000 L beverage. This unit is split into 0.5 L and 1.5 L PET bottles, and the comparison is made between the overall environmental impact between the use of NR-PET and REF-PET. The following assumptions are made:

1. There will be no changes in the distribution from the wholesaler and beverage manufacturer compared to the per cent situation.
2. There will be no changes in consumption, meaning that the customer will ask for the same quantity of the same product, even if the bottle type is changed.
3. The return rate (percentage of bottles sold returned) for soft drink and water bottles will be the same even if the REF-PET bottles are replaced with NR-PET bottles.
4. All bottle manufacturers are using the best available technology (BAT).

Production and recycling of bottles

CO_2 emissions in the production and recycling of bottles result from the production of raw materials and bottles, as well as washing and recycling activities. Emissions are calculated based on the energy mix in the country of production. We assume that half of the production of PET occurs in a Nordic country, while the remaining production takes place in another part of Europe.

Production of PET in Europe causes 0.56 kg CO_2/kWh emissions, while in Nordic countries only 0.21 kg CO_2/kWh. The emission factors for different countries were calculated on the basis of www.klimakalkulatoren.no. Since the calculations were made, the Nordic mix has been lowered to 0.19 kg CO_2/kWh. For processes in Norway, we have used a Nordic average of 0.21kg/kWh, as the Nordic power market is, to some extent, common.

The trip rate reflects the average number of times that a REF-PET bottle is used (refilled) before it is discarded. This rate is dependent on the actual return of bottles (the degree of refund), and to what degree the bottle is suitable for reuse when it is returned (this is checked with technical sorting by the bottling plants). The numbers presented below are based on information from one beverage producer (Coca-Cola).

1. 0.5 litre PET: used 9 times on average
2. 1.5 litre PET: used 12.5 times on average
3. Plastic crates and trays: used 50 times on average

In Norway, refund rates are higher for REF-PET bottles, probably because the range of NR-PET bottles mainly consists of smaller units that deform easily, and lack of knowledge among consumers about the refund system. Based on data collected from Norsk Resirk, the return rate for both bottle types (and both sizes of bottles) is set at 95 per cent. Both sorting and storage of REF-PET bottles are space-intensive. In addition, the cleaning of the bottles also requires energy. Environmental impacts associated with discharges of water resulting from washing processes are excluded because the same type of detergent (mainly caustic soda) is used in the two cleaning processes (Lerche Raadal et al., 2005). Plastic crates (boxes) and trays used for the distribution of bottles, washed in tap contractions, and energy consumption associated with this are also included in the analysis (trip rate = 50).

Both NR-PET and non-usable REF-PET bottles are sent to recycling. Due to an average of 5 per cent obsolescence in each trip for NR-PET bottles, only 56 per cent of PET bottles from the recycling of materials are recovered in the end, the formula being $X=0.95^{\text{number of trips}}$. Collected NR-PET bottles are squeezed in the grocery shops before transported to the Norsk Resirk's plants where they are compressed. The total energy consumption for compressing is approximately 100 kWh per ton of empty bottles.

From Norway, compressed balls of empty bottles are shipped to recyclers in Sweden and Denmark where they are cut into flakes and washed in caustic soda. Both glossy and light blue NR-PET bottles are suitable for the production of new beverage bottles. In recent years, the use of PET in bottle production has significantly increased, and production systems have been designed for bottle-to-bottle recycling.

Some of these systems are highly energy-efficient in reusing the original materials, and these savings will appear in environmental accounts as a deduction. For NR-PET bottles made from 50 per cent original plastic and 50 per cent recycled plastic, the deduction is made for 50 per cent, while for REF-PET bottles made from 100 per cent original plastic, we have credited everything. Furthermore, we have not taken into account that the recycled plastic can be recycled several times and can thus contribute to further reductions in energy use and CO_2. The reason for this is primarily the uncertainty regarding how much of the plastic is recycled again and what it replaces. As long as we assume that recycled bottles are used in a closed system, this uncertainty applies primarily for REF-PET bottles.

A large-scale transition to NR-PET bottles in Norway can lead to the establishment of a national production and recycling facility. Assuming BAT, CO_2 emissions will then be expected to be significantly reduced. The need for transportation of bottles to recycling will also be reduced. The assumptions in the calculation of environmental accounting for the various beverage bottles are summarised in Table 1.

Table 1: Assumptions

	100% NR-PET bottles	**100% REF-PET bottles**
Recycled PET in bottles	50%	0%
Return rate	95%	95%
Trip Figures	1	9 (.5 l) / 12.5 (1.5 l)

In Table 2, the energy consumption at different stages of production and recycling are shown. Energy consumption is the basis for the calculation of CO_2 emissions. The production of a REF-PET bottle requires about five times as much energy as an NR-PET bottle, as REF-PET bottles only consist of virgin plastic and they are also heavier than NR-PET bottles. However, since the bottle can be reused several times, the energy associated with the production of PET bottles per trip is less than half the energy consumption of an NR-PET bottle. Taking into account recycling, saving energy consumption compared with the use of virgin PET, the energy consumption for NR-PET bottles is marginally lower than for REF-PET bottles. The reasons why REF-PET bottles have relatively low gains from recycling are, firstly, that only about 50 per cent of these bottles are collected and recycled and, secondly, that the NR-PET bottle-to-bottle cycle is highly effective.

Table 2: Energy consumption in the various processes for production and recycling of beverage bottles, kWh per 1000 litre beverage

Moment	**100% NR-PET bottles**	**100% REF-PET bottles**
Production of PET	354	151
Production of bottles	21	5
Sorting and washing	3	17
Recycling	-262	-53
Total	**116**	**120**

To calculate CO_2 emissions (as reported in Table 3), we have assumed that half of the virgin PET is produced with CO_2 emissions of 0.56 kg/kWh. The remaining half is produced either in Sweden or Denmark, with CO_2 emission rates of 0.21 kg CO_2/kWh. The same applies for recycling. Recycled PET is produced in Sweden, with a CO_2 coefficient of 0.21 kg/kWh. The production of NR-PET bottles and pre-forms for NR-PET bottles also takes place in Sweden.

For processes in Norway, we have used a Nordic average of 0.21 kg/kWh, as the Nordic power market is, to some extent, common. (The emission factors for different countries can be found at www.klimakalkulatoren.no)

Table 3: Total CO_2 emissions during production and recycling, kg CO_2 per 1000 litre

Moment	**NR-PET bottles**	**REF-PET bottles**
Production of bottles	122.0	51.8
Washing and sorting	0.6	3.5
Recycling of bottles	-87.5	-17.7

Total	**35.2**	**37.6**

Handling in transportation and distribution

Various forms and combinations of plastic crates, plastic trays, paper boards, and shrink plastic are being used in the transportation and distribution of bottles from, for example, Coca-Cola and Telemark Springwater. In Table 4, we have, based on material used, calculated emissions of greenhouse gas for the two bottle types. The main assumptions are listed below Table 4.

Table 4: Kg CO_2 emissions related to production of handling material used in transport and distribution (per 1000 litres)

	NR-PET	REF-PET
Plastics used in production	11.3	10.9
Washing crates **	-	0.1
Manufacturing paperboard	0.1	0 to 0.1
Plastic recycling (collected in store) *	-1.1	-1.3
Total CO_2 emissions	**10.3**	**9.7**

* Based on a Nordic electricity mix, including plastic waste for final disposal
** 70% for material and 30% of the combustion
*** 30% for material and 70% of the combustion

Transportation

Transportation causes a number of environmental effects. The following activities are included in our analysis:

1. Transport of new bottles to the bottling plant

2. Transfer from the bottling plant for storage

3. Distribution from the bottling plant / stock to customer

4. Return transportation of empties (including transportation of empties to sorting)

5. Transport of empties for recycling or recovery

On the basis of the various transport links and transportation needs, we collected data on: 1) different means of transportation, 2) how many litres of beverages are transported per vehicle or container (train/ship), and 3) transportation distance per 1000L transported. Road transportation is the main source of emissions, and it is also the mode of transportation for which we have the best available data. In order to calculate emissions, the number of travelled kilometres is calculated based on detailed information on actual transportation routes and means of transportation for the sample of firms. Transportation distances are then calculated with the tool www.viamichelin.com for road traffic, www.searates.com for sea transportation, and on the basis of data collected from National Rail for rail transportation.

In Norway rail transportation is the common mode for long-distance transportation. There is a substantial extra fee for rail transportation of containers exceeding 16 tonnes. 16 tonnes is therefore the practical weight limit for long-distance transportation. A container weights about 4 tonnes, thus the payload can be no more than 12 tonnes (Source: Coca-Cola). On the short-distance distribution directly to the end customers, Coca-Cola relies on smaller trucks. On the short-distance distribution, they will not reach the weight limit, but they will reach a volume limit.

Table 5: Weight of 1000 litres beverage, including packaging / handling materials (Kg)

Product	**Bottle weight per L**	**D-Packaging weight per L**	**Shipping weight per L**	**Max L per pallet**	**Average number of Pallet L**	**Average weight 1000L beverage**

REF-PET 0.5 L	0.049	0.13	1.231	480	506	1154
REF-PET 1.5 L	0.107	0.066	1.138	512		
NR-PET 0.5 L	0.024	0.03	1.088	648	589	1053
NR-PET 1.5 L	0.043	0.02	1.069	576		
Effect					**+ 16.4%**	**- 8.7%**

Volume effect affects the distribution transport, which has a volume limit today. It can be explained by the fact that the bottle, including transport packaging, takes up less volume. This means that there are more bottles per layer and more layers per pallet. Data was collected from the sample firms on:

1. Transportation of bottles to the bottling plant
2. The transportation between the bottling plant and intermediate storage
3. Distribution
4. Return transportation (REF-PET bottles)
5. Transportation related to exchange of bottles
6. Transportation recycling – recovery

Due to space restrictions, we only provide the most significant tables here.

Transportation of bottles to the bottling plant

The bottles are manufactured in Linköping and transported to Oslo (307 km) by truck. When a new REF-PET bottle is needed, it is transported in full size, while recycled bottles are transported as ampoules, which are blown up during the bottling process. As REF-PET bottles is used 9 times (0,5 litres) or 12,5 times (1,5 litres) (see the chapter on 'Production and recycling of bottles'), and NR-PET of course have to be replaced every time, the difference in fuel consumption is rather small. Our calculations show a difference with CO_2 emissions for REF-

PET being 0.7 kg CO_2/1000L and for NR-PET 0.5 kg CO_2/1000L. This difference in CO_2 emission is caused by the difference in weight between REF-PET and NR-PET bottles, and the extra use of diesel.

Transportation from the bottling plant and intermediate storage

Local distribution is done directly from the bottling plants. Otherwise, bottles are transported by truck, train, or boat for intermediate storage. By weighing the transported volume and distances with the different types of transport, it was found that a container on average transported 53 km by truck, 225 km by electric train, 8 km by diesel driven train, and 161 km by ship (Sources: Coca-Cola, Mack Breweries). There is just a very short distance left with diesel train. Road transport takes place in two containers, each containing 8800 litres of beverage. The results suggest that a transition to NR-PET bottles reduces the transport weight, and emissions are reduced accordingly (8.7 per cent).

Table 6: Basic figures bottling plant – intermediate storage transportation

	Transport volume (litres)	Net cargo weight (tonnes)	Km truck 1000L	Tonnes-km ship 1000L	Tonnes-km electric train 1000L	Tonnes-km diesel train 1000L	CO_2 per 1000L
REF-PET	17,600	20.3	3.0	9	13	0.5	**4** kg
NR-PET	19,200	20.3	2.8	8.4	11.7	0.4	**3.7** kg

Distribution

For distant regions, transportation by truck, train, or boat to intermediate storage is required. We have obtained figures from across the country for kilometres driven and actual fuel consumption of Coca-Cola's distribution vehicles. These figures roughly reflect the Norwegian market. A key assumption is that the distribution of the beverage (mainly done by beverage manufacturers) will not change. We have based our estimates on a distribution truck with a capacity of 22.5 pallets and 15.6 tonne payload (cf. Table 7). These trucks now have a volume limit (Source: Coca-Cola). Since the NR-PET bottles are more volume efficient, the need for transport is reduced. This results in heavier vehicles and marginally higher fuel consumption, but increases the productivity of transport by around 16 per cent.

Transportation of extra empty crates and plastic trays to stores occurs frequently due to a shortage of crates at the stores. This shortage occurs because beverages purchased at kiosks and petrol stations (KBS segment) are generally returned to stores and not to the original point of purchase. Hence, the stores receive more bottles than they sell. From the data obtained in this study, calculations reveal that this, on average, represents 16.3 per cent of the transportation volume by REFREF-PET bottles. Some of these trays are put on top of pallets with full bottles and thus do not require extra transport capacity. We estimate a 50 per cent efficiency gain from this (8 per cent) in a transition to NR-PET bottles, because such bottles are transported in bags and cardboard boxes instead of plastic crates and boards.

Table 7: CO_2 emissions (per 1000L) in distribution

	Litres per pallet	Empties distributed	Weight per truck (kg)	Litres per truck	Km truck per 1000L	Fuel	CO_2 1000L (kg)
REF-PET	480	8.15%	11600	9900	26 km	0.35 l/km	24.7
NR-PET	590 L	0%	14000	13250	20 km	0.38 l/km	19.7

If we divide the total number of kilometres driven by Coca-Cola by their total volume (including hotels, restaurants, and cafés), we find that Coca-Cola currently drives 26 km for distribution of 1000L. If each truck carries 30 per cent more beverages, this distance is reduced to approximately 20 km per 1000L. CO_2 emissions are not reduced equally, as we calculate a rise in the emissions per driven km due to increased weight.

Return transportation of REF-PET bottles

The main difference between the return transport of REF-PET and NR-PET is that REF-PET has to be transported in its original shape in crates. NR-PET is compressed and packed in boxes or plastic bags at the point of refunding, then transported to Norsk Resirk's regional facility where it is further compressed and packed in containers and transported to the facility in Oslo for further processing and shipping to the recycler. Emissions for REF-PET are calculated as 2.4 kg CO_2/1000L (not shown in Table 8) and for NR-PET are 0.7 kg CO_2/1000L, as detailed in Table 8 (Source: Norsk Resirk)

Table 8: CO_2 emissions per 1000L beverage – return transport of NR-PET to recycling

	Km truck (km)	Km electric train (km)	1000 "litres" trans-ported	Net weight (tonnes)	Truck per 1000L (km)	Diesel per km (L)	Total (kg CO_2)
To Norsk Resirk (regional)	64	20	69	2.9	0.9	0.26	0.65
to Norsk Resirk (central)	32	3	540	22.7	0.06	0.48	0.08
Total							**0.7**

Transportation related to exchange of bottles

REF-PET bottles are a mix of bottles associated with specific manufacturers and standardised bottles. When bottling plants bring in the empty bottles, they receive an unsorted mix of the different variants. The main actors, Ringnes and Coca-Cola, carry their bottles to a common sorting facility in Oslo, and receive sorted bottles in return. The return distance between bottling plants and sorting plant is about 18 km (Source: www.viamichelin.com).

In order to assess the carbon emissions from interchange transport, we use information from one company. Based on this information the transportation work split between sea freight, rail and road, and 1000L beverage generates average CO_2 as indicated in Table 9 (Source: Coca-Cola):

Table 9: CO_2 emissions per 1000L beverage - Coca-Cola's interchange transportation

	1000L transport	Net load weight (tonnes)	Tonne/km truck per 1000L	Tonne/km vessel per 1000L	Tonne/km electric train per 1000L	Total CO_2
Interchange transport	17	5.4	6.1	1.7	3.4	4.8 kg

Coca-Cola and Ringnes both cover the whole Norwegian market and have an efficient apparatus for collecting, sorting, and returning the bottles. For bottling plants with lower volumes, this process is not as cost-effective, and generates more transportation costs. Table 10 shows transportation and emissions for two medium-sized bottling plants, Telemark Springwater located in Fyresdal in Telemark and Farris located in Larvik (Source: www.viamichelin.com).

Table 10: CO_2 emissions related to intermission transport generated by Farris and Telemark Springwater (TKV) transport interchange

	Volume (1000L)	Market share (Source: Canadian Soft Drinks Service 2010 Cycle)	Km to Oslo	Km per 1000L	Extra km truck transport in relation to CC	Extra km for the total market (per 1000L)	Extra CO_2 for the total market as of 1000L

TKV	16800	3.7%	498	29.3	24.6	09	0.7
Farris	50000	11.0%	268	15.8	11.0	1.1	0.8
Total						**2.1**	**1.5**

Other manufacturers add minor extra CO_2 emissions for the interchange-related transport, but these are not included in this analysis. We have not taken into consideration that other major beverage manufacturers, such as Hansa, Borg, and Mack, have higher transportation costs and emissions than is the case for Coca-Cola. With the inclusion of emissions from the two manufacturers Farris and TKV (1.5 kg), we find that an estimated total average CO_2 emission of 6.3 kg CO_2 per 1000L beverages distributed is related to the exchange transport of REF-PET bottles. In sum, total emissions of CO_2 in transportation can be summarised as in Table 11.

Table 11: Transportation - Total emissions of Kg CO_2 for 1000L Beverage

Moment	CO_2-emissions NR-PET (Kg/1000L)	CO_2-emissions REF-PET (Kg/1000L)
Installation transport of new bottles	0.5	0.7
Central transport bottling plant for caching	4	4
Distribution/collection of empty bottles	20	25
Return transportation	1	2
Transport exchange	-	6
Transfers to recycling	0.3	<0.1
Total	≈ 25	≈ 38

Sensitivity analysis

There are several key parameters that may be altered in the calculations above. In this chapter, we have simulated how certain alterations of key assumptions affect the estimated CO_2 emissions. The alterations are summarised in Table 12.

Assumptions for the recycling process

Table 12 indicates that repeated recycling of PET benefits the NR-PET bottles, at least given that the energy savings in the recycling of these bottles are high, and higher than the energy savings achieved by the recycling of REF-PET bottles. If the proportion of recycled plastics in NR-PET bottles is 100 per cent, the CO_2 emissions will be reduced by 5 kg/1000L beverage. (Due to shrinkage in the use of bottles and the recycling process, we assume that there must be 10 per cent initial (virgin) plastic in the production of PET). However, if the proportion of recycled plastic is reduced to 30 per cent, the CO_2 emissions for NR-PET bottles will increase by 2.6 kg. REF-PET bottles will have approximately the same emissions.

Changes in return per cent and number of trips

The difference in CO_2 emissions between the two bottle types is related to how many times the REF-PET bottles are reused. If the number of trips for REF-PET bottles is increased by two, the reuse of such bottles will have slightly lower CO_2 emissions than NR-PET bottles. However, if the number of trips is reduced by two, CO_2 emissions for REF-PET bottles increase by approximately 6 kg. If we assume that the energy savings for recycling are equal for both types of bottles, and that this process only requires 25 per cent of the energy required by the use of virgin plastic, the related CO_2 emissions will increase substantially. However, they will decrease slightly for REF-PET bottles.

Table 12: Sensitivity analysis, changes in Kg CO_2 emissions per 1000L beverage distributed

Assumption	Only NR-PET bottles	Only REF-PET bottles
Transportation basis (cf. Table 11)	25.8	37.7
Assumptions in the recycling process:		
PET recycled several times (30% recovered each round)	-15.5	-7.7
100% recycled PET in NR-PET bottles	-4.7	-
30% recycled PET in recycled bottles	+2.6	-
Similar savings by recycling	+20.4	-2.3
Amended return rate		
97.5%	-5.2	-6
90%	+10.2	+7.8
Changed number of trips		
High (11 for 0.5 l, 15 for 1.5 l)	-	-4.3
Low (7 to 0.5 l, 10 for 1.5 l)	-	+6
PET recovery and production facility in Norway		
Changed energy	-13	-
Reduced transportation	-0.8	-
Other transport sensitivity analysis		
Reduced frequency distribution (increased storage capacity)	-2.5	-
5 layers with a 1.5 L bottle recycling (vs. 4)	-2.6	-
0.05 L fuel consumption/km per tonne (versus 0.11 L/km)	1.2	1.8

Establishing a recycling plant for bottles

If a Norwegian production and recycling facility is established, it can be assumed that the savings from recycling are the same for both bottle types. If the bottle to be recycled consists of 90 per cent recycled PET, the emissions from NR-PET bottles will then be approx. 20 kg/1000L beverage, but 35 kg from REF-PET bottles. A transition to 100 per cent recycled bottles (NR-PET) could imply that it is viable to establish a recycling and manufacturing facility for PET bottles. The most significant change in CO_2 emissions would then be associated with the transition from European coal energy to the Nordic electricity mix with a prominence of hydropower, and the reduced need for transport.

Utilization of free storage space (reduced transportation frequency)

Bottling plants include empties (bottles purchased in the KBS segment) in their return transport. The stores' dedicated storage space will be halved compared to using REF-PET bottles, and the delivery frequency can also be halved. It does not really matter if the reduction in frequency is taken out for beverages or other goods. Alternatively, the freed space can be used to increase the shop space. The main point in this context is that the change can be attributed to a transition to NR-PET bottles. (Our calculations do not include CO_2 emissions from constructing the new facilities in Norway.)

Conclusion

The total CO_2 emissions are summarised in Figure 1. On the production side, we see that the recycling containers have significantly higher emissions from the production itself, but that this will be compensated for by the benefits from recycling. Transport packaging for NR-PET bottles has higher emissions than for REF-PET bottles because this packaging requires more raw materials than the current recycling bins. Figure 1 shows that the emissions from the two types of bottles are relatively equal when it comes to production and transport packaging. Hence, the transportation activities account for the differences:

- NR-PET bottles are transported more efficiently in terms of both weight and volume.
- Distribution of REF-PET bottles requires transportation of extra crates because of an unbalanced return of bottles between grocery stores and gas stations and kiosks.
- Transportation related to the exchange of bottles is not needed for NR-PET bottles.

When we calculate the total impact of our analysis for the Norwegian market (Bryggeri- og drikkevareforeningen, 2010), we find that 100 per cent REF-PET bottles will cause emissions of 39,000 tonnes of CO_2, while NR-PET will cause 32,000 tonnes, a reduction of 7000 tonnes (18 per cent).

On the basis of the findings in this study, the main actors in the Norwegian grocery industry now strive to change the Norwegian toll regulations on beverage bottles. Once the regulations are altered, there will be a major transition from REF-PET to NR-PET bottles in the Norwegian market.

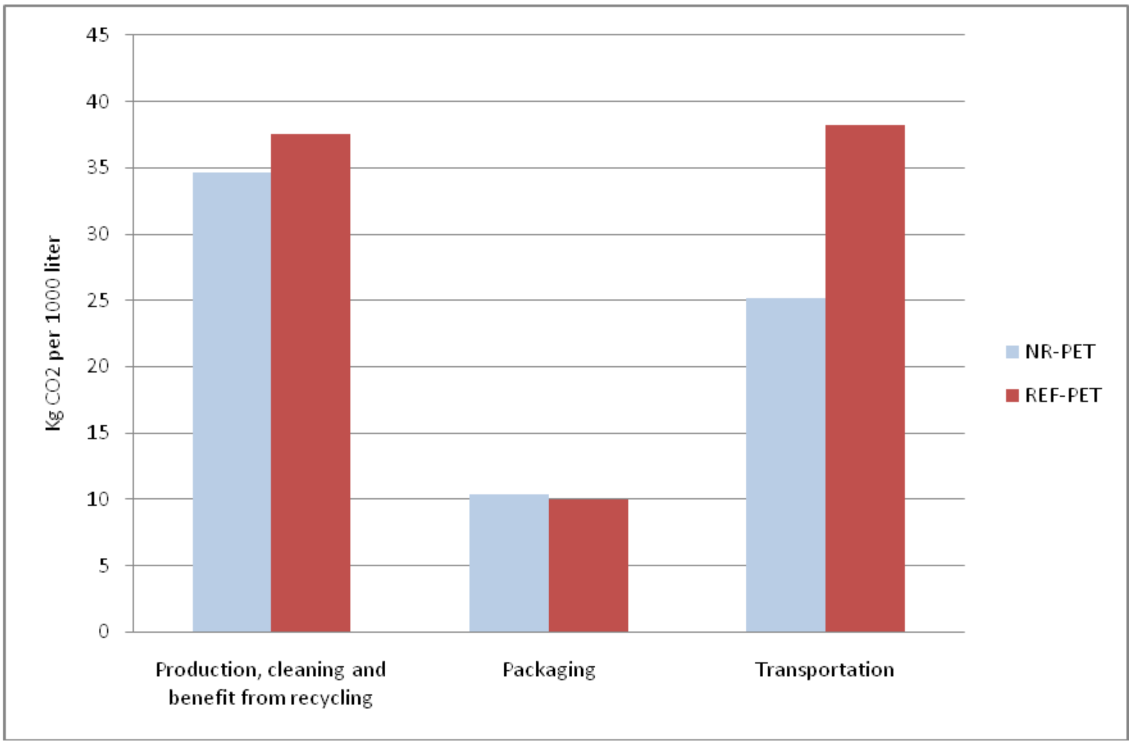
This research did not require more than 15 interviews with knowledgeable key informants, but of course, numerous hours were also spent on collecting other types of information and working with the data. Writers, including Allen, O'Callaghan and Lee (1995) and Ayres (1996), have warned that life-cycle analysis is problematic because there are issues related to data, expenses, and time needed. We suggest that it does not need to be so difficult, and hopefully, other researchers will seriously consider this approach in future research.

Limitations and further research

There are some obvious uncertainties with regard to the study findings. Firstly, it was assumed that recycling is a highly energy-efficient activity. Secondly, it was not taken into account that recycled plastics can be recycled several times. Thirdly, it was assumed that the current distribution pattern remains the same. Fourthly, as REF-PET bottles are compared to NR-PET bottles, combinations thereof are ignored and, hence, possible thresholds cannot be identified.

For transportation, unresolved issues related to a shift from REF-PET to NR-PET bottles are: 1) How does this shift affect the logistics in distribution centres? 2) How can freed return capacity best be utilized? and 3) How is the freed space for bottle sorting and storage of empties best utilized? Furthermore, increased transported volumes create the need to establish a reception and production facility for NR-PET bottles.

Figure 1: Grouped overview of CO_2 emissions in the number of kg of beverages 1000L



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