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Decomposition analysis of Dutch beverage packaging waste
An analysis of material efficient innovations

Maryse M.H. Chappin[a,*], Marko P. Hekkert[a], Robbert van Duin[b]

[a] *Department of Innovation and Environmental Sciences, Utrecht University, Heidelberglaan 2, 3584 CS Utrecht, The Netherlands*
[b] *Bureau B&G, Pollenseveenweg 11, 8166 HT Emst, The Netherlands*

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Abstract

Decreasing the amount of waste that can be allocated to packaging has been prominent on the political agenda in the Netherlands for two decades. In this period, both policy and innovations have influenced the way products are packed and how the resulting waste is managed. The aim of this study is to gain more insight in how individual material management options have led to a change in the amount of final waste in the Netherlands in the period 1986–1999. For this purpose, we use a so-called decomposition analysis, which is widely used in energy studies, and apply this to the case of beverage packaging waste. The analysis shows a decomposition of the final waste in four different packaging materials (carton, glass, metal and plastic) and creates insight in the effects of (1) the change in product consumption, (2) the material substitution, (3) the change in packaging size, (4) the lighter packaging concepts, (5) the product re-use and (6) the material recycling. The main conclusion is that in the period 1986–1999, the largest reductions in final waste production were realized with product re-use and material recycling.

Keywords: Decomposition analysis; Material efficient innovations; Beverage packaging; Waste reduction

* Corresponding author. Tel.: +31 30 253 6196; fax: +31 30 253 2746.
E-mail address: m.chappin@geog.uu.nl (M.M.H. Chappin).

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1. Introduction

Since the end of the 1970s packaging and packaging waste is perceived as an important environmental topic. In the Netherlands, more than 300 companies voluntarily signed an agreement with the government to reduce the amount of packaging material and to stimulate recycling. These appointments were laid down in ‘Convenant Verpakkingen I’ in 1991. In 1994 the directive ‘Packaging and Packaging Waste’ was drawn up by the European Union. This directive had to be implemented by each member of the EU. The members are able to decide how they want to realize the objectives of the directive. As a consequence, the directive is implemented differently in the various member EU states (SVM-PACT, 2002). In the Netherlands, the implementation of the directive has taken place by means of a ministerial regulation: ‘Packaging and Packaging Waste’. Waste prevention and recycling are key elements of the Dutch waste policy (OECD, 1998). The regulation requires the efficient use of 65% of all packaging introduced on the market before 30th of June 2001. Besides, it states the opportunity to accomplish a voluntary agreement between government and packaging industry to reach the regulation goals if this has (financial) benefits. The result was ‘Convenant Verpakkingen II’ signed on 15 December 1997 (VROM, June 2001).

During the years, several innovations have taken place. Some causing less, others causing more packaging waste. In Table 1, the objectives and results of Convenant Verpakkingen II are represented. According to this table, we can conclude that the central objective to limit the amount of final (landfilled and/or incinerated) packaging waste at a maximum of 940 kiloton is realized. Also, the objective concerning prevention is realized. Whereas, the objective for material recycling is not realized. This becomes clear when the results for each type of material are considered. The results for plastic and metal are near the intended results, but paper/cardboard and glass are clearly behind. Several aspects of the objectives of Convenant Verpakkingen II will be discussed. The prevention objective, for example, does not concern an absolute prevention of 10% in 2001 compared to 1986, because it is

Table 1
Objectives and results of Dutch Packaging Convenant II, for the period 1998–2001 (Commissie Verpakkingen, 2002; SVM-PACT, 2002)

Objectives for 2001	Results 1998	Results 1999	Results 2000	Results 2001
Final waste max. 940 kiloton	987 kiloton	924 kiloton	834 kiloton	924 kiloton
10% prevention	22%	23%	29%	27%
65% material recycling	61%	64%	65%	61%
Recycling per material				
85% Paper/cardboard[a]	70%	71%	71%	66%
90% Glass	79%	80%	80%	78%
80% Metal	79%	78%	78%	78%
27% Plastic[b]	14%	18%	23%	24%

[a] It concerns all paper/cardboard; also non-packaging. Both categories, packaging as well as non-packaging, have a target of 85% for material recycling. The target for beverage cartons is 15% material recycling. Stichting Hedra has send a letter of intent to the Minister to collect as much cartons as necessary to meet this target (VROM, 1997).

[b] There is a complementary exertion obligation of 8% material re-use, besides this obligation of 27% material re-use.

corrected for economic growth. Furthermore, the combustion of plastic in a coal-fired plant is not classified as incineration, but as useful application and is ascribed to the complementary exertion obligation of 8% material recycling.[1]

Even though Table 1 creates some insight in the dynamics of packaging waste in the Netherlands, it hardly shows any underlying factors that have led to a decrease in the amount of final waste. Examples of these underlying factors are: how is the final waste influenced by a rise in consumption and a change in material use? Also the net effect of material recycling on final waste reduction does not become clear since it can be influenced heavily by material substitution.

A better insight in the underlying factors that cause the packaging waste is necessary to understand exactly what happened in the packaging sector that has led to less final packaging waste. Furthermore, these insights are helpful to evaluate policy results in greater detail. This is useful in the formulation of new policy initiatives. The aim of this paper is to present a decomposition analysis of the Dutch packaging waste in order to create more detailed insights in the factors that have influenced the amount of final packaging waste. The research is restricted to beverage packaging waste in the Netherlands. The reasons for this choice are two-fold: First, the beverage-packaging sector contains several material and many material management options are possible in this sector (see Hekkert et al., 2000). Second, the data availability for this sector is quite good, at least better than for other sectors.

In 1999 beverage packaging was responsible for a share of 11% of the total amount (in kiloton) of (new) packaging in the Netherlands. With respect to the amount of final waste beverage packaging represented a share of 10% in the Netherlands in 1999 (Bergsma et al., 2001). The general goals (see Table 1) of the Convenant Verpakkingen II are not translated in specific goals for product-packaging combinations, but a few objectives in the Convenant Verpakkingen II have been formulated specifically for beverage containers. In the case of the product groups ‘beer’ and ‘sodas and mineral water’ more-way packaging cannot be substituted by one-way packaging unless the burdening of the environment is less or at least equal of the one-way packaging compared to the more-way packaging (with the exception of 2% of their total sale). Besides, there is a special target for beverage cartons; 15% material recycling (VROM, 1991) (see also footnote ‘b’ Table 1).

In the next section, the methodology will be discussed. First, some background information on the decomposition analysis is given, then the operationalization and method formulation used for this research will be described. In Sections 3 and 4, data and results will be shown and explained. Finally, discussion and conclusion can be found in Sections 5 and 6, respectively.

2. Methodology

The goal of a decomposition analysis is to separate changes, for example, energy use, into contributions from several specified factors. Ang (1995) developed a framework for decomposition method based on 51 decomposition analyses. To carry out the analysis, a

[1] In this research, all incineration of plastic is allocated to final waste.

four-step procedure is often followed. In the first step, data defined at a specific level of sector disaggregation is collected. In the next step, an existing decomposition method is selected or a new one is proposed. Subsequently, in the third step the method is applied. The final step involves the use of the results to explain the observed changes (Ang, 1995). This methodology is originally developed and applied for energy systems. For the decomposition method (step 2), three common approaches are the energy consumption, the energy intensity and energy elasticity. Ang (1995) has presented a general framework with these three approaches in which the formulation of each approach is done additively as well as multiplicatively. An additive decomposition measures the change between two years, while the multiplicative decomposition presents the ratio of one year to that of another (Ang, 1995). See Farla and Blok (2000) for an application of the additive method. The analysis (step 3) may be periodwise or a time-series one. The latter uses time-series data to get a yearly decomposition. The periodwise analysis, on the other hand, does not consider the intervening years of the period and only uses data for the first and last year of the period (Ang, 1995).

This research focuses on material use instead of energy use. Therefore, this methodology needs some adaptations before applying it to material use. The next two sections contain the operationalization of the first three steps of the four-step procedure and the method formulation, respectively.

2.1. Operationalization

The following five beverages will be investigated: ‘soda and mineral water’, ‘beer’, ‘wine’, ‘juices’ and ‘liquid dairy products’. ‘Distillates’ are not investigated due to a lack of data about the packaging used for the sale of distillates. ‘Sport drinks’ are not investigated since they were not on the market in the beginning of the investigated period. The proportion of the latter two beverage categories in the total is small, so the omission of these beverages is justified. For each beverage the use of different materials is analyzed. The materials used for packaging of beverages are glass, carton, plastic and metal. So this research disaggregates on the level of different materials (step 1 in Ang, 1995 method). An important aim of the Convenant Verpakkingen is to minimize the amount of packaging waste that will be incinerated and/or landfilled (final waste). Therefore final packaging waste will be the approach (step 2) in this research. The analysis will be periodwise (step 3) where the period lasts from 1986 to 1999. This period is chosen because 1986 represents the basis year of the Convenants I and II and 1999 is at the end of the duration of Convenant Verpakkingen II. The actual end is 2001, but the lack of availability of data for 2001 induced this choice to use 1999.

2.2. Method formulation

In this section, the formula used for the analysis will be described. The formula will be constructed step by step. Consider a packaging i manufactured from material j used for beverage d. The starting point of the analysis is that we define a representative packaging concept i that was in use in 1986. Then we analyze the changes in this representative packaging concept over time. For every packaging concept we determine the packaging-weight per volume content of packaging I, which is done by dividing the weight of packaging i by its volume.

Next the sale of beverage *d* in packaging *i* is analyzed in 1986. Therefore the consumption of beverage *d* is multiplied by the percentage of consumption that is sold in packaging *i*.

Because the packaging weight per liter and the quantity of liters are known, the total amount of packaging material *j* for packaging *i* can be calculated by multiplying both numbers.

In some cases returnable packaging is used. It is then necessary to divide the amount of packaging material *j* by the trip number, because less packaging is needed. Eq. (1) covers the above-mentioned:

$$\mathrm{PMU}_{1986} = \sum_{d} \sum_{j,d} \sum_{i,j,d} \left[x_{i,j,d} * C_{d,1986} * \left(\left(\frac{Vm_{i,j,1986}}{Vv_{i,j,1986}} \right) \Big/ T_{i,j,1986} \right) \right] \tag{1}$$

where PMU is the packaging material used, C_{d} the consumption of beverage *d*, *d* the different beverages, Vm_i the weight of packaging *i*, *j* the different materials, Vv_i the volume of packaging *i*, *i* the different packaging, T_i the trip number packaging *i*, and $x_{i,j,d}$ the percentage consumption of packaging *i*.

In order to calculate the amount of packaging material that was final waste (incinerated and/or landfilled waste) correction of Eq. (1) for material recycling is desirable. Formula (2) presents the relation between material recycling and waste disposal:

$$\text{Percentage recycling} + \text{percentage final waste} = 100\% \tag{2}$$

The percentage final waste depends on the percentage of collection of packaging *i* and in the case of a returnable packaging on the trip number. It is calculated as follows:

$$\mathrm{FW}_{i,j,d,1986} = \left(\frac{100 - z_{i,j,1986}}{100} \right) * T_{i,j,1986} \tag{3}$$

where FW is the percentage final waste, z_i the percentage collecting of packaging *i*, T_i the trip number packaging $i = 100/((100 - z_i) + y_i)$, and y_i the percentage drop out after collection of packaging *i*.

For the Dutch situation it is assumed that the percentage that is not separately collected will be final waste and that the drop out after collection will be recycled. This appears when Eq. (3) is rewritten. The total drop out is the denominator of the fraction in Eq. (4):

$$\mathrm{FW}_{i,j,d,1986} = \frac{100 - z_{i,j,1986}}{100 - z_{i,j,1986} + y_{i,j,1986}} \tag{4}$$

where FW is the percentage final waste, z_i the percentage collecting of packaging *i*, and y_i the percentage drop out after collection of packaging *i*.

Concluding, by integrating formulas (1)–(4), the amount of final packaging waste in 1986 (FPW_{1986}) can be calculated in the following way:

$$\mathrm{FPW}_{1986} = \sum_{d} \sum_{j,d} \sum_{i,j,d} \left[x_{i,j,d,1986} * C_{d,1986} * \left(\frac{(Vm_{i,j,1986} / Vv_{i,j,1986})}{T_{i,j,1986}} \right) * \left(\left(\frac{100 - z_{i,j,1986}}{100} \right) * T_{i,j,1986} \right) \right] \tag{5}$$

where FPW is the final packaging waste, C_d the consumption of beverage *d*, *d* the different beverages, Vm_i the weight of packaging *i*, *j* the different materials, Vv_i the volume of packaging *i*, *i* the different packaging, T_i the trip number packaging *i*, $x_{i,j,d}$ the percentage consumption of packaging *i*, and z_i the percentage collecting of packaging *i*.

Actually, in Eq. (5) the amount of packaging material used (PMU) is multiplied by the percentage that becomes final waste.

Several factors influence the rise or fall of final packaging waste in a certain time frame. It concerns the following factors:

- *cons*. Change in consumption: When a change in the consumption occurs more or less packaging is needed, resulting in more or less packaging waste.
- *subs*. Substitution of packaging material: When packaging material is substituted by lighter or heavier material, this results in either less or more kiloton of packaging waste respectively.
- *mup*. Change of material use per unit of packaging: When a packaging is innovated, for example, it is made thinner, less material is needed per packaging and therefore causing less packaging waste.
- *qpl*. Change in quantity of packaging units per liter: The packaging waste of a smaller consumption unit is relatively seen more than the packaging waste of a large consumption unit. So, introducing smaller consumption units will result in more packaging waste.
- *re-use*. Change in product re-use: When the re-use of a packaging increases, less packages are needed to pack the same quantity. This results in less packaging waste.
- *recy*. Change in material recycling: When more material is recycled, less virgin material is needed and less final packaging waste arises.
- *muf*. Change of material use per unit of functional product: When a product is concentrated, less of it is needed to fulfill the same function. Therefore, less packaging is needed, resulting in less packaging waste.

The next step is to develop a formula in which the contributions from these factors to the change in the final packaging waste become visible. This is done in Eq. (6):

$$\begin{aligned} \mathrm{FPW}_{1999} = \sum_{d}\sum_{j,d}\sum_{i,j,d} & \left[\left(\mathrm{FPW}_{i,j,d,1986} * \left(1 + \frac{C_{d,1999}}{C_{d,1986}}\right)\right)\right. \\ & * \left(1 + \left(\frac{x_{i,j,d,1999} - x_{i,j,d,1986}}{x_{i,j,d,1986}}\right)\right) \\ & * \left(1 + \left(\frac{(Vm_{i,j,d,1999}/Vv_{i,j,d,1999}) - (Vm_{i,j,d,1986}/Vv_{i,j,d,1986})}{(Vm_{i,j,d,1986}/Vv_{i,j,d,1986})}\right)\right) \\ & * \left(1 + \left(\frac{(1/T_{i,j,d,1999}) - (1/T_{i,j,d,1986})}{(1/T_{i,j,d,1986})}\right)\right) \\ & \left. * \left(1 + \left(\frac{\mathrm{FW}_{i,j,d,1999} - \mathrm{FW}_{i,j,d,1986}}{\mathrm{FW}_{i,j,d,1986}}\right)\right)\right] \end{aligned} \tag{6}$$

where FPW is the final packaging waste, C_d the consumption of beverage d, d the different beverages, Vm_i the weight of packaging i, j the different materials, Vv_i the volume of packaging i, i the different packaging, T_i the trip number packaging i, $x_{i,j,d}$ the percentage consumption of packaging i, and FW the percentage final waste.

Three factors are responsible for changes in the packaging weight per liter (Vm/Vv): Change in material use per unit of packaging, change in quantity of packaging units per liter and because of changes in material use per unit functional product. Simplification of Eq. (6) induces the following:

$$\mathrm{FPW}_{1999} = \sum_{d}\sum_{j,d}\sum_{i,j,d}[\mathrm{FPW}_{i,j,d,1986} + \mathrm{cons}_{i,j,d} + \mathrm{subs}_{i,j,d} + \mathrm{mup}_{i,j,d} + \mathrm{qpl}_{i,j,d} + \mathrm{muf}_{i,j,d} + \mathrm{reuse}_{i,j,d} + \mathrm{recy}_{i,j,d}] \quad (7)$$

where FPW is the final packaging waste, d the different beverages, j the different materials, i the different packaging.

The analysis will be conducted according to formula (6). But before the results of this analysis are presented, the data input for the analysis will be given in the next chapter.

3. Data input

In this section, the necessary data to fill in formula (6) of the previous section are given. Tables 2 and 3 represent the specifications of each respective packaging concept that was used in the period 1986–1999. The required specifications are weight, trip number, percentage of collecting, percentage final waste and percentage material recycling. Table 2 presents the data for 1986 and Table 3 for 1999.

Table 4 states the consumption volume of the different beverages categories. Furthermore, the packed volume in each packaging concept is stated for 1986 and 1999.

Table 5 shows the quantity of packaging units that is produced to pack the given consumption in Table 4. For refillable packages correction has taken place by dividing the quantity of packaging units by the trip number (see Tables 2 and 3).

4. Results

In this section, the results of the decomposition analysis are shown. Per beverage the main changes for the period are given, after which a figure is shown, based on Eq. (7).[2]

4.1. Wine

In 1986 glass was used to pack wine. This has not changed during the period. The same bottle of 0.75 l was used in 1999. It is noticeable that the collection rate of these bottles has increased during the years from 57 to 92%. Fig. 1 shows the decomposition analysis for wine.

[2] See Tables 2–4 for the references used per packaging type.

Table 2
Packaging specifications 1986

Packaging	1986				
	Weight[a]	Trips	Percentage of collecting (%)	Percentage final waste[b]	Percentage material recycling[c]
Glass soda: 1 l	900 g (1.5 g alum and 0.5 g PVC) [1]	25 [1]	98 [7]	50	50
Glass milk: 1 l	600 g (0.3 g alum) [1]	30 [1]	98 [7]	60	40
Glass juice: 1 l	390 g (4 g steel and 0.5 g PVC) [1]	1 [1]	57[d]	43	57
Glass: 250 cm^3					
Glass: 300 cm^3	361.5 g (2 g steel)[e]	40 [7]	99 [7]	40	60
Glass: 750 cm^3	400 g [1]	1 [1]	57[d]	43	57
Glass: 1 l	900 g (1.5 g alum and 0.5 g PVC) [1]	1 [1]	57[d]	43	57
PET: 1.5 l					
Glass: 500 cm^3					
PC bottle: 1 l					
Carton milk: 1 l	25 g carton (5 g PE) [1]	1 [1]	0 [1]	100	0
Carton juice: 1 l	22 g carton (1.5 g alum and 5.7 g PE) [1]	1 [1]	0 [1]	100	0
Can 100% alum: 330 cm^3					
Can steel/alum: 330 cc	35 g [3]	1 [1]	0 [1]	57	43 [6]

References: [1] Jansen et al., 1990; [2] Bergsma et al., 2001; [3] SKB, 2001; [4] CBK, 2002; Centraal Brouwerij Kantoor, e-mail Robert Seegers, 16 December 2002; [5] Stichting Promotie Glasbak, 2002; [6] Stichting Kringloop Blik, e-mail Ubbens Ubbo, 3 December 2002; [7] assumption.

[a] The weights of the cap and/or inner layer are given between brackets.

[b] The percentage final waste (except for cans) is calculated with the following formula: $Y = (100 - \text{percentage of collecting}) * \text{number of trips}$. (see Section 2.2).

[c] The sum of percentage final waste and the percentage recycling is 100%.

[d] Calculated as follows: Y = percentage collected glass 1986 [5] * (percentage collected green glass 1999 [2]/percentage collected glass 1999 [5]) = 49.5 * (92/80) = 57%.

[e] A new bottle (257 g [4]) was introduced on 1 November 1986. The replacement of the old bottle (367 g [4]) had to be finished on 1 April 1987 (Roessel, 1985). So, the time available for the replacement was 5 months, of which two in 1986 and three in 1987. On average 20% of the bottles was replaced each month. In the first 10 months of 1986 the old bottle was used for 100%. In November this was 80% and in December this was 60%. Therefore the average weight of the beer bottle in 1986 was: 10/12*367 + 1/12*0.8*367 + 1/12*0.2*257 + 1/12*0.6*367 + 1/12*0.4*257 = 361.5 g.

In the first column, the packaging waste of 1986 is given. As mentioned above, only glass bottles were used to pack the wine. The consumption of wine in the Netherlands was higher in 1999 than it was in 1986. This results in more packaging waste (column 2). But because more bottles were collected in bottle banks in 1999 compared to 1986, more glass was recycled. This is visible in the third column. Overall this results in a level of considerably less final packaging waste in 1999 compared to 1986 (column 4).

4.2. Beer

Two types of packaging were used to pack beer in 1986 as well as in 1999. It concerns a steel can and a refillable glass bottle with deposit. A new bottle with a weight of 70% of the

Table 3
Packaging specifications 1999

Packaging	1999				
	Weight[a] (Bergsma et al., 2001)	Trips (Bergsma et al., 2001)	Percentage of collecting (Bergsma et al., 2001) (%)	Percentage final waste[b] (%)	Percentage material recycling[c] (%)
Glass soda: 1 l Glass milk: 1 l Glass juice: 1 l	900 g (2 g steel)	30	98	60	40
Glass: 250 cm^3	240 g (2 g steel)	40	98	80	20
Glass: 300 cm^3	257 g (2 g steel)	40	99	40	60
Glass: 750 cm^3 Glass: 1 l	400 g	1	92	8	92
PET: 1.5 l	108 g (3 g PP)	25	99.8	5	95
Glass: 500 cm^3	28 g (3 g PP)	1	0	100	0
PC bottle: 1 l	74 g (2 g PE)	30	99	30	70
Carton milk: 1 l	24.5 g carton (3.5 g PE)	1	0	100	0
Carton juice: 1 l	24.5 g carton (2 g alum and 8 g PE)	1	0	100	0
Can 100% alum: 330 cm^3	14.6 g	1	0	70	30 (Bergsma et al., 2001)
Can steel/alum: 330 cm^3	28.9 g	1	0	22	78 (Bergsma et al., 2001)

[a] The weights of the cap and/or inner layer are given between brackets.
[b] The percentage final waste (except for cans) is calculated with the following formula: $Y = (100 - \text{percentage of collecting})*\text{number of trips}$. (see Section 2.2).
[c] The sum of percentage final waste and the percentage recycling is 100%.

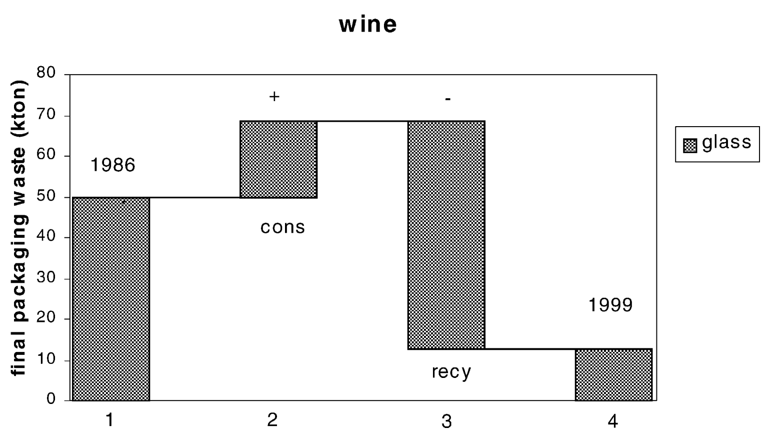

Fig. 1. Decomposition analysis of wine (cons = change in consumption, recy = change in material recycling).

Table 4
Division of beverage sales in million liters

Packaging	Soda and mineral water		Beer		Juices		Liquid dairy products[a]		Wines	
	1986 [1,5]	1999 [2]	1986 [3]	1999 [2]	1986 [1]	1999 [2]	1986 [1]	1999 [2]	1986 [4]	1999 [2]
Glass soda: 1 l	890	11								
Glass milk: 1 l							412	0		
Glass juice: 1 l					14	4				
Glass: 250 cm^3	0	102			0	56				
Glass: 300 cm^3			823	808						
Glass: 750 cm^3									216	298
Glass: 1 l										
PET: 1.5 l	0	1038								
Glass: 500 cm^3	0	65								
PC bottle: 1 l							0	162		
Carton milk: 1 l							1522	1454		
Carton juice: 1 l	0	114			261	311				
Can 100% alum: 330 cm^3	0	16								
Can steel/alum: 330 cm^3	99	195	35	121						

References: [1] Jansen et al., 1990; [2] Bergsma et al., 2001; [3] Centraal Brouwerij Kantoor. telephone calls Robert Seegers, 25 November 2002 and 5 December 2002; [4] Centraal Bureau voor de Statistiek, 2002; [5] Verpakken, 1986.

[a] The assumption is made that the density of liquid dairy products is 1 kg/l.

Table 5
Amount of packaging units produced in millions[a]

Packaging	Soda and mineral water		Beer		Juices		Liquid dairy products		Wines	
	1986	1999	1986	1999	1986	1999	1986	1999	1986	1999
Glass soda: 1 l	36 (890)	1 (11)								
Glass milk: 1 l							14 (412)	0		
Glass juice: 1 l					14	1 (4)				
Glass: 250 cm^3	0	11 (408)			0	6 (224)				
Glass: 300 cm^3			69 (2743)	68 (2693)						
Glass: 750 cm^3									288	398
Glass: 1 l										
PET: 1.5 l	0	28 (692)								
Glass: 500 cm^3	0	130								
PC bottle: 1 l							0	6 (162)		
Carton milk: 1 l							1522	1454		
Carton juice: 1 l	0	114			261	311				
Can 100%alum: 330 cm^3	0	48								
Can steel/alum: 330 cm^3	297	585	105	363						

[a] The number between brackets represents the amount of packaging units needed and only differs from the amount of packaging units produced when a refillable packaging is used. Therefore only for the case of a refillable packaging a number between brackets is given.

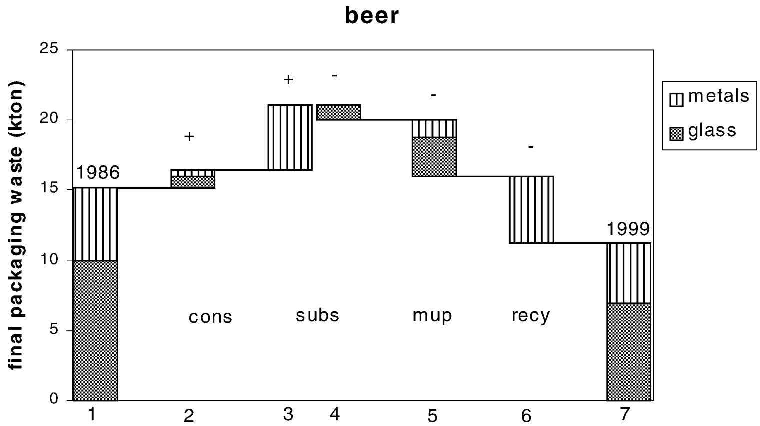

Fig. 2. Decomposition analysis of beer (cons = change in consumption, subs = substitution of packaging material, mup = change of material use per unit of packaging, recy = change in material recycling).

old one was introduced at the end of 1986 (Roessel, 1985). As a consequence old as well as new bottles were on the market in 1986. A year later in 1987 all bottles were replaced, so in 1999 only the light bottle is used.[3] The crown cap of the bottle has not changed during the years, but the steel can has also changed, it has become thinner during the years (SKB, 2001). The top of the can, including the opening lid, is made out of aluminum.

In Fig. 2, the results for beer can be found. Again the final packaging waste in 1986 is shown in the first column. As mentioned earlier, in both years the beer was packed in glass bottles and in metal cans. Glass was used for most of the packaging of beer (96%) and is responsible for the largest share in the waste in 1986. Glass is heavy, but the packaging waste per trip is restricted as a consequence of re-use. The amount of metal consists of a quantity derived from the can and a quantity derived from the crown-cap. As a consequence of the rising consumption of beer, more packaging material is needed (column 2). But as presented in columns 3 and 4, the distribution of the sales are changed. More beer is being packed in cans (column 3) and less in glass (column 4). Nonetheless the relative share of glass is still higher.

Moreover, changes in the amounts of final waste are caused by a reduction of material use per packaging for the metal can as well as for the bottle of glass. This results in less packaging waste (column 5). It has to be considered that the reduction for glass has taken place at the very beginning of the period.

The last factor that is responsible for differences between 1986 and 1999 is a change in material recycling. In the incineration plants, more metal is separated with the help of magnets and recycled in 1999 (78% in 1999 compared to 43% in 1986). The aluminum (from the top of the can) is not recycled. This change in material recycling is visible in column 6. The final effect of all the changes becomes clear in column 7 in which the amount of final packaging waste in 1999 is represented. The total amount of 1999 is about half the amount of 1986. The greatest reduction has appeared in the waste of glass.

[3] The use of one-way glass is assumed to be negligible.

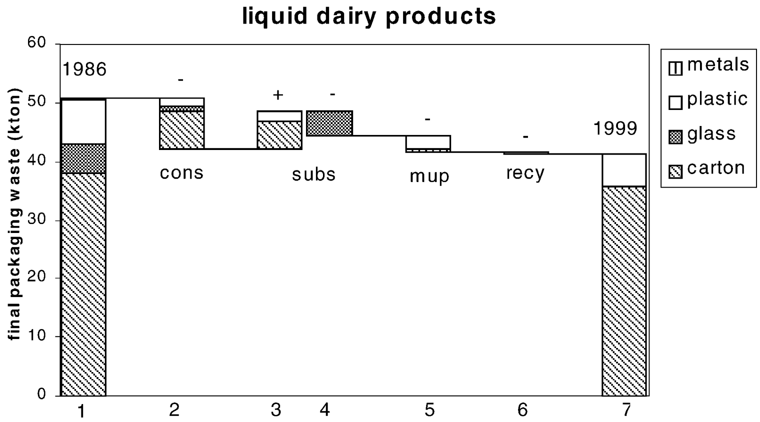

Fig. 3. Decomposition analysis of liquid dairy products (cons = change in consumption, subs = substitution of packaging material, mup = change of material use per unit of packaging, recy = change in material recycling).

4.3. Liquid dairy products

The liquid dairy products were sold in a refillable glass bottle and in a carton pack in 1986. Besides the glass to produce the bottle, aluminum for the cap was used as well. The carton pack consisted of carton and polyethylene (PE). In April 1996 a new bottle made out of polycarbonate was introduced (Albada, 1995). This is a refillable bottle with a trip number of 30. Fig. 3 contains the decomposition analysis for liquid dairy products.

The final waste in 1986 (column 1) consists mainly of carton. This is due to the facts that most milk was sold in carton packs and that the amount of glass per volume unit is low due to refillable bottles. The inner layer of the carton pack, which was made out of plastic, was responsible for the plastic flow. The caps of the glass bottles contributed little to the metals waste.

Due to a decrease of the yearly consumption of liquid dairy products less packaging was needed and consequently the amount of waste was also lower for 1999 (column 2). However, other factors were responsible for the differences as well. Glass was not used for dairy packaging any longer in 1999. The carton pack and the polycarbonate bottle, that was introduced as mentioned above, substituted this packaging (columns 3 and 4). The trip number of the polycarbonate bottle was the same as the trip number of the glass bottle, namely 30.

Additionally, the material use per carton pack was reduced. Less carton and less PE were used in 1999 than in 1986. This is shown in column 5.

The last factor was the increase in material recycling. Because the polycarbonate bottle was collected separately in the retail stores, the drop out that occurred during the cleaning was recycled due to a clean and high-quality waste flow. This was responsible for a slight reduction of the final waste in 1999 (column 6).

Finally, this resulted in an amount of final packaging waste for 1999 that was lower than in 1986, whereby glass and metal were not presented anymore and the amount of carton and plastic was a little less (column 7).

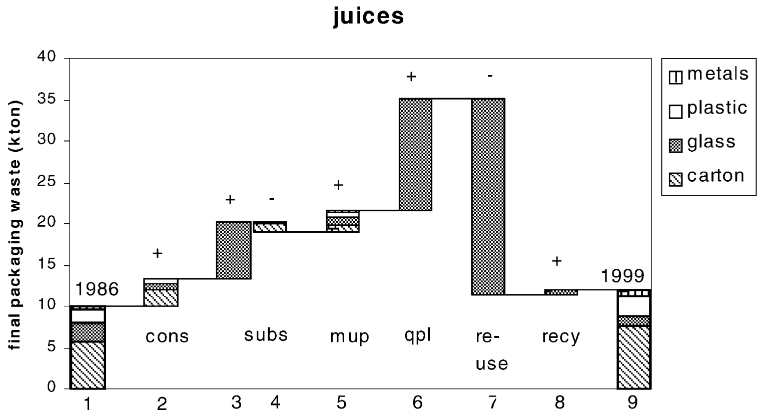

Fig. 4. Decomposition analysis of juices (cons = change in consumption, subs = substitution of packaging material, mup = change of material use per unit of packaging, qpl = change of quantity of packaging units per liter, re-use = change in product re-use, recy = change in material recycling).

4.4. Juices

For the packaging of juices two types were used in 1986, such as carton pack and glass bottle. The carton pack was different to the one used for dairy products (see also Tables 2 and 3). An aluminum layer was put inside to prevent oxygen and light to react with the juice.

In the period investigated a new type of packaging came into practice, which resulted in the introduction of a smaller consumption unit of the glass bottle. This smaller bottle was being re-used as opposed to the larger one.

As shown in Fig. 4 in 1986 the largest part of the juices was packed in carton packs. This explains the quantity of carton and plastic in column one. The inner layer of the caps of the glass bottle contributed to the plastic waste. The amount of metal consisted of the caps of the glass bottles and the aluminum inner layer of the carton pack. In column 2, the consumption growth of juices is visible in the increase of the waste.

A change in the composition of the waste occurred because the sale of glass packed juices rose at the cost of carton packed juices. This is shown in columns 3 and 4.

It is remarkable that the carton pack has grown in weight, despite the objective of prevention. More carton, more aluminum foil and more PE were used for the production of a pack. This results in an increase of waste (column 5). For the sale of glass packed juices two packaging concepts were used. One is the 1-l bottle. This bottle, except the cap, is also somewhat heavier than the bottle of 1986. The material used for the cap has been reduced, but the metal prevented by the use of the lighter cap has been undone by the use of more aluminum foil for the carton pack (column 5).

The other packaging concept for glass concerns a new little bottle with a volume of 250 cm^3. In column 6, it is evident what the consequences are of this new packaging. More packaging is needed to pack 1 l. But this packaging is a refillable packaging. As a consequence of the trip number of 40 less material is needed to pack 1 l. In column 7 this result of re-use is presented. The largest part of this decrease has consequently arisen because this little bottle was re-used and the smaller part because the larger bottle was also re-used in 1999.

The bottles are collected in the retail stores. This collection rate is 98%. Few of these collected bottles dropped out and were used for material recycling. Consequently, less material (kiloton) went to the recycling than was the case in 1986 when the bottles were collected in a bottle bank and all the collected glass went to the recycling (column 8).

All these factors mentioned above influenced the amount of final packaging waste in 1999, causing a little increase compared to 1986 (column 9).

4.5. Soda and mineral water

The consumption of soda and mineral water has grown the most compared to the other beverages. The consumption in 1999 is slightly more than 160% compared to the consumption in 1986. In 1986 almost 90% of the consumption was packed in a refillable glass bottle (1 l) with deposit. Additionally, cans were used to pack 10% and the remaining percent was packed in a one-way glass bottle.

This changed during the years and in 1999 different packaging concepts were used. The glass bottle has been substituted to a large extent by a 1.5-l PET bottle. This refillable bottle was already introduced in 1989 (Roessel, 1989). In 1999, this bottle was used to pack 64% of the soda and mineral water. Another PET bottle was put in the market, a one-way PET bottle of 0.5 l. This bottle was introduced in 1998 and had a share of 4% in 1999.

The glass packaging concepts used for packaging soda and mineral water were, for a large extent substituted, by refillable glass bottles (1 l) and small glass bottles (250 cm^3), also used for the packaging of juices. The larger bottle was used to pack 1% and the smaller bottle, mainly used in the hotel and catering industry, was used to pack 6%. Besides PET and glass, metals were used. The steel can for soda and mineral water changed in the same way as for beer. But also another can was used to pack a little share, a lightweight can made of aluminum. At last carton was also used in 1999. The carton pack, used to pack juices, was also used to pack soda and mineral water. In Fig. 5 the results are shown.

Column 1 represents the amount of the different packaging materials used in 1986. The enormous growth of the consumption is shown in the second column. Because of the changes in the use of packaging concepts, explained above, column 3 shows an increase in the waste of carton, plastic and metal and column 4 a decrease of glass.

In column 5, it is visible that the material use per packaging unit was also different in 1999 compared to 1986. The changes of the steel can were responsible for the decrease of waste.

More material is needed because smaller consumption units were used. Column 6 consists of an increase in glass and metal. The use of 250 cm^3 bottles is responsible for this increase. Relatively more glass is needed per bottle and instead of one cap, four caps are needed to pack a liter.

In the column labelled re-use, the consequences of the increase of the trip number is visible; the trip numbers of the small bottle of 250 cm^3 (40 trips) and of the 1.0-l bottle (30 trips) were higher in 1999 than the trip number of the 1.0-l bottle in 1986 (25 trips).

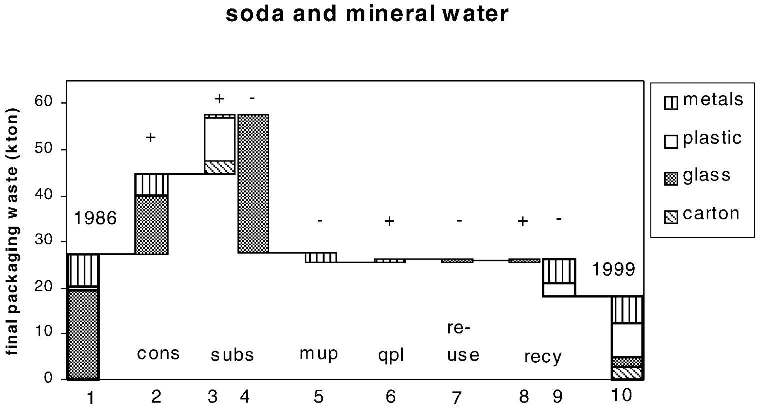

Fig. 5. Decomposition analysis of soda and mineral water (cons = change in consumption, subs = substitution of packaging material, mup = change of material use per unit of packaging, qpl = change of quantity of packaging units per liter, re-use = change in product re-use, recy = change in material recycling).

Columns 8 and 9 show the contribution of changes in material recycling to the changes of the waste. More metals and plastic were recycled (column 9). The stream of metal consists of steel and aluminum. The recycling of aluminum is more difficult than the recycling of steel and therefore the recycling percentage of aluminum is lower than the percentage of steel (30% compared to 78%). The steel can be separated with the help of magnets, while the aluminum is separated by means of eddy currents. The plastic originated from the refillable bottle, because the drop out of the collected bottles was clean enough for recycling. The increase of column 8 occurred because the collection of the glass bottle was constant (98%) and the trip number of it rose (from 25 to 30).[4]

Finally, this results in an amount of final packaging waste in 1999 as given in column 10. The total amount is less compared to 1986 and the quantity of plastic and carton has risen at the expense of glass.

5. Discussion

The conduction of the decomposition analyses provided interesting insights in the underlying factors that have influenced changes in final packaging waste for beverages in the Netherlands in period 1986–1999. Although this methodology has originated from energy use analysis, the results of the analysis are useful for the understanding of individual contribution of different material management options. The results unveil which options realize most reduction of final packaging waste and are therefore relevant for policymaking.

[4] The trip number is calculated with the following formula (see also Section 2.2): $T_i = 100/((100 - z_i) + y_i)$, where y_i is the percentage drop out after collection of packaging i and z_i the percentage collection of packaging i. Relatively less material will be recycled when the trip number rises and the collection rate is constant. This is also explained in Section 5.

During this research, it was necessary to make some assumptions and choices. This has an impact on the reliability and usefulness of the results. These assumptions and choices and their supposed impact on the results will be discussed in the following paragraph.

The first uncertainty concerns part of the data for the year 1986. Trip numbers and percentages of collecting from literature were used to calculate the waste figures.[5] Therefore, it is useful to determine the influence of the trip number and the percentage of collection on the waste figures. The trip number is dependent on two parameters: the percentage of collecting and the drop out during the re-use process (see also Section 2.2). In Table 6 it is shown how the amount of 'packaging material used' and the amount of 'final packaging waste' of 1986 change when these parameters (collection rate and drop out re-use) are varied and the trip number is constant and when these parameters are varied and the trip number is not constant. The 1-l glass bottle for soda is taken as an example.

First of all, when the 'trip number' is held constant and the 'percentage of collecting' and drop out after re-use are varied the amount of 'final packaging waste' changes. However, the amount of 'packaging material used' does not change. An increase or a decrease of 1 in the percentage of collecting results in a decrease or increase respectively of 50% in the amount of final packaging waste. When the percentage of collecting increases or decreases with 2%, this results in a decrease or an increase, respectively, of 100% in the amount of final packaging waste. The explanation for these outcomes is the following: because the trip number (=25) is constant in the scenarios, the total drop out (=4% per trip) is also constant. The drop out is the sum of bottles, which are not collected (final waste) and of bottles, which may not be used any longer (drop out during re-use process). The former bottles become final waste, the latter bottles will be recycled. So, the 4% drop out per trip is divided between these two options since the trip number is constant.[6]

However, it is likely that the percentage of collecting and/or the drop out during the re-use process may differ during the years. That would result in different trip numbers. Therefore, it is also shown in Table 6 how the amount of final packaging waste changes, when the trip number varies due to a changing percentage of collecting and a changing drop out during the re-use process. It becomes clear that if the percentage of collecting decreases, the trip number will be lower and so the amount of packaging material used will be larger. As a consequence, the amount of final packaging waste will also be larger. If the percentage of collecting would drop from 98 to 95%, this would have a large impact on the final packaging waste, namely an increase of 154%. Thus, small differences in collection rate have very large influence on the amount of final waste. This implies that our calculations of final waste of 1986 are strongly influenced by this rate.

[5] When these numbers were not available assumptions have been made for the collection of packaging types and/or for the trip number of these packaging types. It concerns the glass bottle for soda, the glass bottle for milk and the small bottle for beer. These assumptions have been made considering the data for 1999 and therefore should be seen as realistic.

[6] When the percentage of collecting is 100% the percentage final waste will 0% (0*25 = 0) and when the percentage of collecting is 96% the percentage final waste will be 100% (4*25 = 100). These latter two scenarios are not realistic because it is not likely that the consumer collects 100% or that there is no drop out during the re-use process.

Table 6
The impact of changes in a trip number, a percentage of collecting and/or drop out on final packaging waste; the example of the 1 liter glass bottle for soda

Scenario	Trips	Percentage of collecting (%)	Drop out re-use (%)	Percentage final waste[a] (%)	Percentage material recycling[b] (%)	Packaging material used 1986	Final packaging waste 1986
Reference	25	98	2	50	50	31.7 kiloton	15.8 kiloton
Percentage of collecting −1%, drop out re-use −1%	25	97	1	75	25	31.7 kiloton = +0%	23.7 kiloton = +50%
Percentage of collecting +1%, drop out re-use +1%	25	99	3	25	75	31.7 kiloton = +0%	7.9 kiloton = −50%
Percentage of collecting −1%	20	97	2	60	40	39 kiloton = +25%	23.7 kiloton = +50%
Percentage drop out re-use +1%	20	98	3	40	60	39 kiloton = +25%	15.8 kiloton = +0%
Percentage of collecting −1%, Percentage drop out re-use +1%	17	97	3	50	50	46.6 kiloton = +47%	23.3 kiloton = +47%
Percentage of collecting −2%	17	96	2	67	33	46.6 kiloton = +47%	31.2 kiloton = +97%
Percentage drop out re-use +2%	17	98	4	33	67	46.6 kiloton = +47%	15.4 kiloton = −3%
Percentage of collecting −2%, Percentage drop out re-use +2%	13	96	4	50	50	60.9 kiloton = +92%	30.4 kiloton = +92%
Percentage of collecting −3%	14	95	2	71	29	56.5 kiloton = +78%	40.1 kiloton = +154%
Percentage drop out re-use +3%	14	98	5	29	71	56.5 kiloton = +78%	16.4 kiloton = +4%
Percentage of collecting −3%, Percentage drop out re-use +3%	10	95	5	50	50	79.1 kiloton = +150%	39.6 kiloton = +151%

[a] The percentage final waste is calculated with the following formula: $Y = (100 - \text{percentage of collecting}) * \text{number of trips}$ (see Section 2.2).
[b] The sum of percentage final waste and the percentage recycling is 100%.

If the drop out during the re-use process increases, the trip number will also be lower and therefore the amount of packaging material used will be higher. But in that case the absolute amount of final packaging waste varies hardly (−3, 0 or 4%).

Finally, when the percentage of collecting decreases and the drop out during the re-use process increases, the decrease of the trip number will be even stronger and even more packaging material will be used. The amount of final packaging waste will be larger.

However, significant changes in 1986 final packaging waste do not affect the relative influence of the different packaging concepts that are reviewed.

A second uncertainty is the distribution of the sale of juices and soda and mineral water. It is necessary to remark that the data of 1986 were from around 1986. Besides, it is assumed that all the plastic packaging for liquid dairy products in 1986 were meant to pack yoghurt with the consequence that no plastic was used for the packaging of liquid dairy products because yoghurt was not considered as a liquid dairy beverage in this study. This is done on the basis of information available in this sector. The impact of these assumptions is valued low due to the relative small size of this packaging volume.

Finally, the choice to conduct a periodwise analysis instead of a time-series analysis has also an impact on the usefulness of the results. The investigated period is long and some innovations took place at the beginning of the period, even before Convenant Verpakkingen I and Convenant Verpakkingen II were signed, but this does not become visible in the figures itself. In a time-series analysis this problem would not have occurred. In the explanation of the figures it is mentioned if the innovations have taken place early. According to this it is possible to use the results to evaluate the Dutch policy. A more detailed periodwise analysis was not possible due to a lack of data availability.

As mentioned earlier, the used method resulted in useful outcomes and created insight in the individual contributions of the underlying factors. Therefore, the method is useful for studies like this. But because of some uncertainties in the data the results should be handled with care. Although they create insight in the contributions of different the underlying factors, these should be seen as *relative* contributions more than *absolute* contributions.

6. Conclusion

The aim of this research was to achieve insight in the underlying factors that causes Dutch beverages packaging waste. To achieve this insight a decomposition analysis was carried out. It turned out to be a useful method for the determination of the contributions of the underlying factors. According to the results of the analyses several things were found.

In general, the amount (in kiloton) of final packaging waste of beverages in the Netherlands was lower in 1999 than in 1986. But not all changes that have taken place led to a reduction of the use of packaging material and of the final packaging waste. The main conclusions will be given for the each of the underlying factors (change in consumption, substitution of packaging material, change of material use per unit of packaging, change of quantity of packaging units per liter, change in material use per functional product, change in product re-use and change in material recycling).

The consumption growth caused an increase in the need for packaging, which resulted in an increase in final packaging waste. Except for the consumption of liquid dairy products, which decreased. The consumption of all other beverages increased.

The contribution of substitution consists of several effects. First of all, substitution of refillable glass by refillable plastic (for example, soda and mineral water) resulted in less packaging because of the lower weight of the plastic bottles. The substitution of refillable glass by one-way metal cans caused an increase in material use. But because of an increased material recycling (see below) this effect was undone and did not result in more final packaging waste. The use of the carton pack instead of a refillable bottle resulted in more final packaging waste, because this is a one-way packaging. Finally, in the case of juices an increase in the use of glass was shown. But because of the use of a refillable bottle instead of a one-way packaging (see below) this did not result in more final packaging waste. So, the largest reduction of the final packaging waste as a consequence of substitution was realized by the replacement of refillable glass with refillable plastic.

The changes of the material use per unit of packaging caused in most cases a lower amount of final packaging waste (see steel can). But in some cases (see carton pack juices) the material use per unit packaging increased and therefore caused more final waste. The contribution of this factor, compared to other factors, is not very large, but should not be neglected. It can be a useful innovation for the reduction of the final waste of one-way packaging.

The introduction of smaller consumption units, which is reflected in the factor quantity of packaging units per liter, caused more packaging waste, as one would expect. But the contribution was relatively small. The largest contribution was due to the introduction of the small glass bottle. But due to refillability the increase of final waste was limited (see below).

A change in material use per functional product has not occurred during the investigated period. The contribution of product re-use was large instead. This effect becomes obvious in the case of juices. As mentioned above, more glass was used to pack juices. This would have resulted in an increase in final packaging waste, if the bottle was not refillable. Because of this refillability the packaging waste per trip is low; less virgin material is needed, so less final waste arises.

More glass, metal and plastic (from the refillable plastic bottles) was recycled. This increase in material recycling contributed to an important reduction of the final packaging waste.

Although re-use and recycling are already key elements of the Dutch waste policy, further stimulation of these two factors is important, because their relative contribution to reducing final waste has been very high, according to the results. Especially product re-use can be considered important since the effect is significant and only a limited number of packaging concepts are responsible for this effect.

Based on these results, the current trend in the Dutch beverage packaging system is worrying, since an obvious trend in changing from re-use towards single use packaging concepts is visible. Besides, most of the non-beverage packaging is one-way packaging. Therefore, large reduction may be realizable in these sectors (non-beverage packaging). For further research it would be interesting to apply the decomposition analysis also to these sectors, but as it has been observed in this research, very detailed information is necessary to obtain some accurate results.

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