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TNO report

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Single use Cups or Reusable (coffee) Drinking Systems: An Environmental Comparison

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Summary

The question “What is better for the environment, drinking coffee out of a disposable or reusable cup?” has already been the subject of study in the past. In the early nineties, TAUW Milieu undertook the studies “Reusable versus Disposable” and “Recycling Polystyrene (coffee)cups, sense or nonsense?!” These concerned environmental analyses where the following systems were compared:

– Cup and saucer (porcelain, reusable)
– Cup (cardboard, disposable)
– Cup (polystyrene, disposable; 0% recycling)
– Cup (polystyrene, disposable, 25% recycling)

The method for environmental comparison used in the said studies was not yet complete and in addition there was some discussion regarding the data and assumptions adopted. At the present time, various methods are available for a comparative environmental analysis that are generally accepted in the Netherlands and elsewhere. Changes have also occurred with regard to the drinking cups themselves, the possible washing up of cups and waste processing. Because the question “What is better for the environment, drinking coffee out of a disposable or reusable cup?” still has a certain topicality, the Stichting Disposables Benelux has commissioned TNO to conduct an updated environmental comparison.
The objective of the investigation was consequently to update the said TAUW studies (including examination of the influence of changes observed). This concerns the LCA methods applied, the assumptions adopted and the values of the various parameters used to make the different comparisons. In addition, the sensitivity of the LCA results to certain assumptions or parameter values was evaluated.

Part I; in conformity with the ISO 14040 and ISO 14044 standards

To compare systems equally to with each other, they have to be placed under the same denominator. This is done by defining the so-called functional unit that describes the function to be undertaken by the systems in a clear, quantitative way. The function is to provide hot drinks from a drinks vending machine or dispenser in an office or factory environment. The functional unit examined in this connection is as follows:

The dispensing of 1000 units of hot drinks (tea/coffee/hot chocolate) from a vending machine or dispenser in an office or factory environment.

The drinking systems compared in the present study are:
- Reusable porcelain cup and saucer
- Reusable earthenware mug
- Disposable polystyrene cup
- Disposable polystyrene insert cup with reusable cup holder
- Disposable paper cup.

Generally spoken, these systems are representative for the Western European situation. The environmental analysis includes:
- Production of raw materials
- Production of disposable and reusable systems
- Use of the systems (cleaning of the cup and saucer/mug where applicable)
- Collection of disposable or reusable systems used (including the specific collection transports)
- Waste processing and recycling
- Transport of materials and of cups to the customer and transport to recycling and waste processing
- Cleaning of reusable systems also includes the treatment of waste water in a sewage purification plant (RWZI).

The effect categories concerned in undertaking the environmental analysis are:
- Abiotic mineral resources depletion potential (ADP)
- Global warming potential (GWP)
- Ozone depletion potential (ODP)
- Human toxicity potential (HTP)
- Fresh water aquatic eco-toxicity potential (FAETP)
- Marine aquatic eco-toxicity potential (MAETP)
- Terrestrial eco-toxicity potential (TETP)
- Photochemical ozone creation potential (POCP)
- Eutrophication potential (EP)
- Acidification potential (AP)

The LCA was carried out in accordance with the procedure described in the ISO 14040 series.
ISO 14040 permits comparisons of alternative drinking systems only by individual effects category. This comparison is illustrated with the aid of Figure S1.

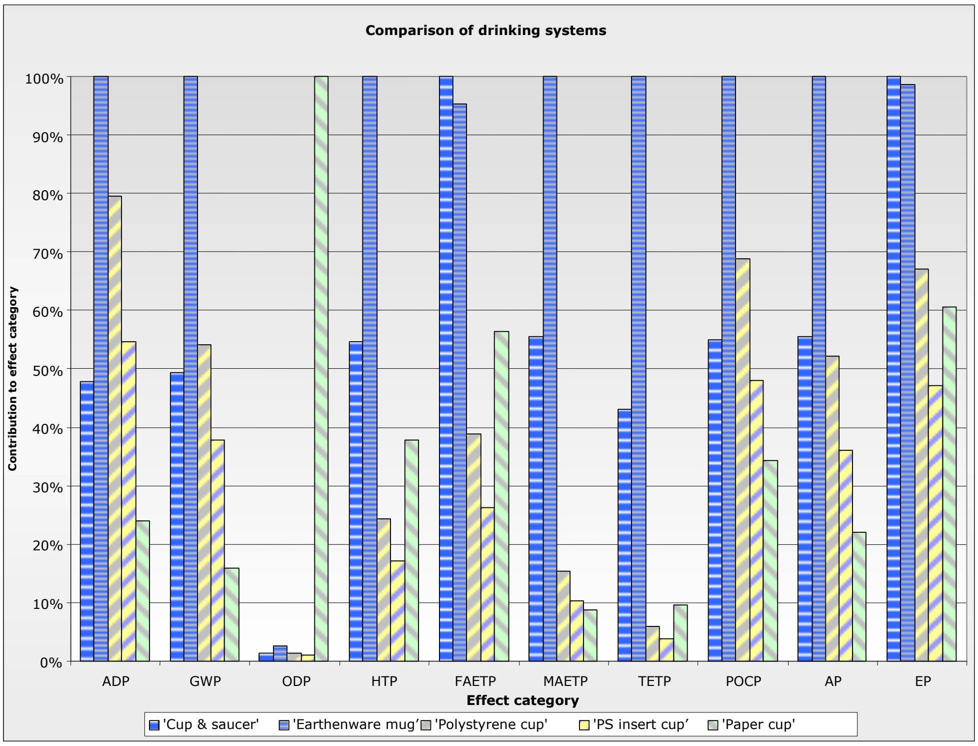

Figure S1 Comparison of the five drinking systems examined.

The scores as shown indicate that the reusable earthenware mug is the most environmentally polluting system in seven (ADP, GWP, HTP, MAETP, TETP, POCP and AP) out of the 10 categories. The reusable porcelain cup and saucer scores the highest for two categories (FAETP and EP).
For ODP, the disposable paper cup scores highest of all. The disposable paper cup is the least environmentally polluting system in 5 out of the 10 categories (ADP, GWP, MAETP, POCP and AP). For the other five categories, the disposable polystyrene insert cup is the least environmentally polluting system. The disposable polystyrene cup does not score highest nor lowest when considering the scores for the ten categories.

However, when comparing the various drinking systems, account must be taken of the major uncertainties in variation in the values of the key parameters, such as period of utilisation of the porcelain cup and saucer or earthenware mug, the method of washing up, waste processing of disposable systems, etc.

No final conclusions can therefore be drawn a priori from the comparisons shown in Figure S1. Sensitivity analyses were therefore carried out.

The following subjects were evaluated in a sensitivity analysis:
- Number of utilisation times of reusable porcelain cup and saucer
- The cleaning frequency of reusable systems; porcelain cup and saucer or earthenware mug
- Energy use of dishwasher
- The use of a professional (industrial) dishwasher
- Water and energy consumption when washing up a reusable earthenware mug oneself
- The cup weight for the disposable systems
- Number of utilisation times made of the disposable systems
- Allocation of the recycling of plastics based on economic value
- Alternative end-of-life routes for disposable polystyrene (insert) cups (100% waste incineration or 100% sub-coal use).

The results of the sensitivity analyses show that cleaning the cup and saucer and earthenware mug for the reusable systems is of very strong influence on the environmental burden by these drinking systems, with a contribution of between 90 and 100%. The utilisation of the porcelain cup (varying between 500 and 3,000 times used) only slightly affects the environmental profile of this drinking system.

For the disposable systems, the production of raw materials and the production of the cup itself very largely determine the environmental profile. Using the cup more often and/or reducing the cup weight therefore has a positive influence. Recycling into regranulate, incineration in a waste incineration plant or energy recovery in a power plant by sub-coal use all have a clearly favourable effect on the environmental profile for the disposable polystyrene (insert) cup.

Part II; not in conformity with the ISO 14040 and ISO 14044 standards

The environmental effects are aggregated by means of the shadow prices method. Shadow costs express the environmental burden of a product or other system in a monetary unit: the Euro. They are based on the shadow price per environmental effect category and by using the shadow prices method, various environmental effect categories can easily be aggregated (the advantage of this method is that it dovetails with the use of market-conforming instruments). The shadow price per effect category is based on emission reduction objectives for the substances covered by the category concerned and on the cost of emission reducing measures that must be adopted per unit in order to achieve the objective. The shadow price in this case is the price per unit of emission reduction for the most expensive measure still to be adopted to achieve the objective.

The aggregated shadow costs for the drinking systems compared are shown in Figure S2.

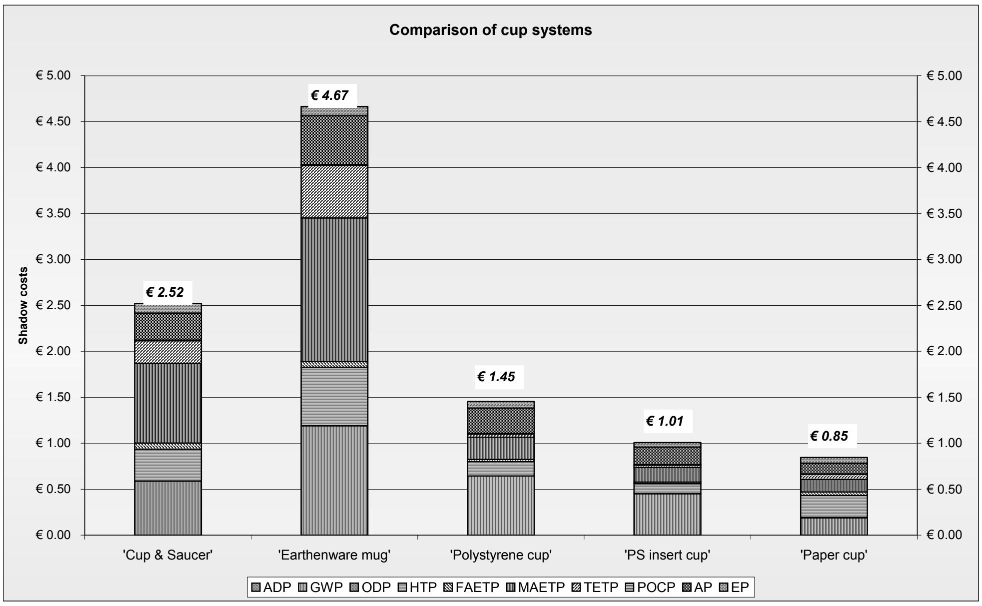

Figure S2 Comparison of the five coffee and other drinking systems investigated on the basis of shadow costs.

A comparison of the drinking systems investigated shows that the reusable mug is the system with the highest environmental impact at a shadow cost of € 4.67. The reusable mug is followed by the reusable porcelain cup and saucer (€ 2.52). For these two systems, the differences with the other systems are always more than 20%. They are followed by the disposable polystyrene cup (€ 1.45) and then by the disposable polystyrene insert cup (€ 1.01). The disposable paper cup scores lowest (€ 0.85)

As the cleaning frequency of the reusable systems reduces, these systems will score more equally when compared with the disposable systems; see Figure S3.

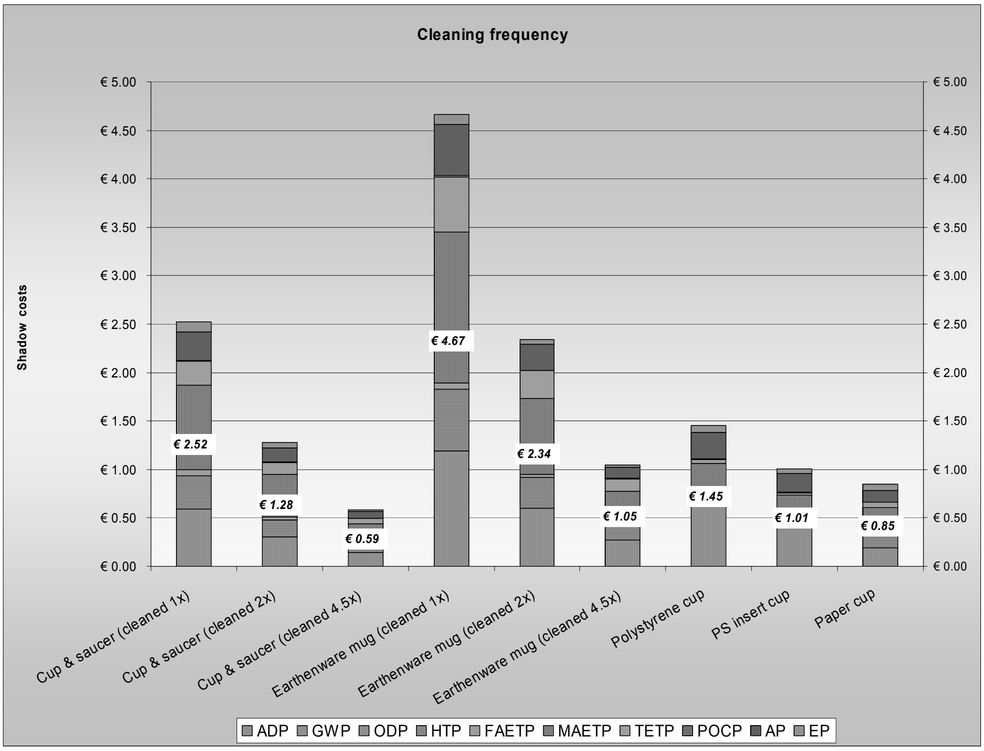

Figure S3 Influence of the change in cleaning frequency[1] of the reusable systems on shadow costs. Under the basic scenario, reusable systems are cleaned after each use. In the sensitivity analysis, (cleaned 2x) means cleaning after being used twice, (cleaned 4.5x) means cleaning after being used 4.5 times on average.

[1] In light of the Hazard Analysis and Critical Points (HACCP) principles, question marks can be placed regarding the hygiene of the system when the cleaning frequency is strongly reduced as this increases the hazard for the consumer [37].

The same trend can be observed when the energy consumption of washing up is reduced. On the other hand, if the disposable cup is used more often, it continues to perform clearly better than the reusable systems; see Figure S4.

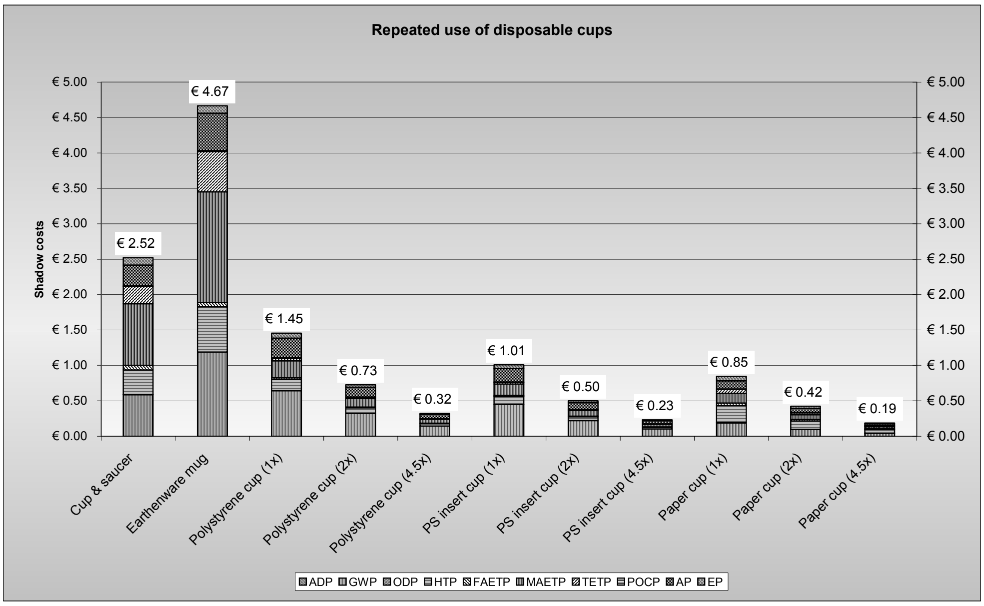

Figure S4 Influence of increased use of the disposable cups on shadow costs. Under the basic scenario, the disposable cups are used only once. Alternatives are: '2x' used twice '4.5x' used 4.5 times.

A reduction in the weight of disposable cups also results in an immediate reduction of the integral environmental burden. In addition to the disposable polystyrene vending cup and the disposable PS insert cup, the disposable PS drinking cup is also used in practice (2.8 – 3.2 grams). Because its weight lies between that of the disposable polystyrene vending cup and that of the PS insert cup, the environmental performance of a disposable PS drinking cup will score between that of the disposable PS vending cup and that of the disposable PS insert cup.

The way in which the end-of-life route of the disposable polystyrene (insert) cup is employed affects the integral environmental burden; see Figure S5. Use of cups as fuel (sub-coal) in a power plant has a favourable effect on the environmental performance. The sub-coal route is therefore strongly recommended for the future.

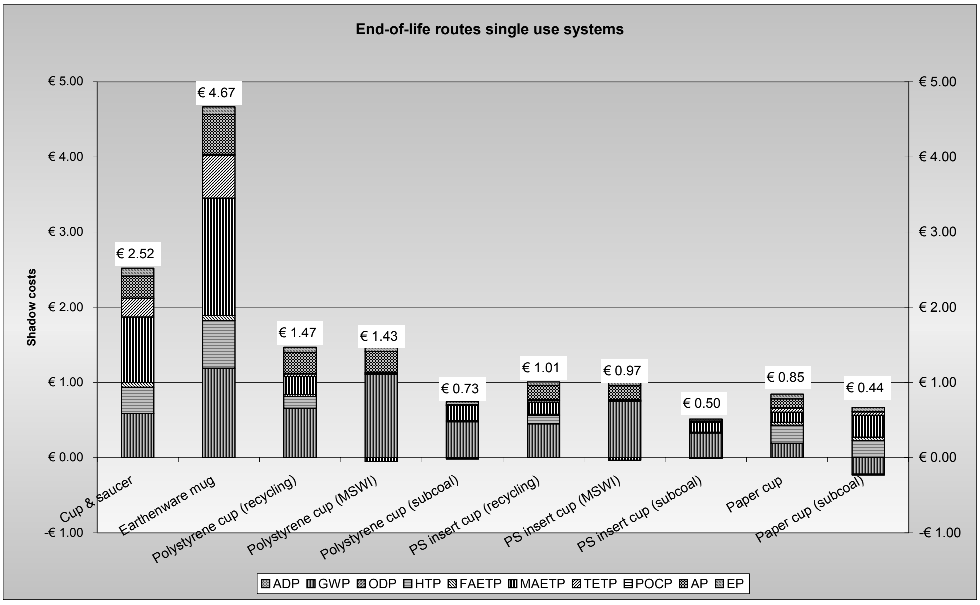

Figure S5 Influence of the choice of end-of-life scenario for disposable PS (insert) and paper cups. Disposable PS (insert) cups are recycled in the basic scenario, while the paper cups are incinerated in an MSWI.

Conclusions (Part I and Part II)

The main conclusion from the present study is that it has become clear that the way in which the individual user uses the reusable or disposable systems directly influences the score of the total drinking system. For the reusable porcelain cup and saucer and for the reusable earthenware mug, cleaning directly influences the level of environmental burden. The frequency of cleaning and use of energy per cleaning are crucial here. Because the user is left plenty of freedom for this, the ultimate burden on the environment is therefore strongly user-related. The life time of the porcelain cup and saucer (is varied from 500 to 3,000 times utilisation) influences to a lesser degree the environmental profile of this (coffee) drinking system. It is also a fact for disposable systems that the user largely determines the ultimate environmental burden by the number of times the disposable cup is used.

The question “What is better for the environment, drinking coffee out of a disposable or reusable cup?” can therefore only be answered on the basis of the specific operating situation.

The results of the comparisons made, based on the shadow prices method, clearly point in the direction that disposable (coffee) drinking systems being the least environmentally burdening.
It is therefore recommended that a weighing-up is made per individual user situation with regard to an eventual choice.

Contents

1. Introduction

The question “What is better for the environment, drinking coffee out of a disposable or reusable cup?” has already been the subject of study in the past. In the early nineties, TAUW Milieu produced the studies “Reusable versus Disposable” [1] and “Recyling Polystyrene (coffee) cups, sense or nonsense?!” [2]. These concerned environmental analyses in which the following systems were compared:
- Cup and saucer (porcelain, reusable)
- Cup (cardboard, disposable)
- Cup (polystyrene, disposable; 0% recycling)
- Cup (polystyrene, disposable, 25% recycling).

The methods for environmental comparison used in these studies were not yet entirely ready and, in addition, there was some discussion regarding the data and assumptions adopted. At the present time, various methods are available for comparative environmental analysis that are generally accepted in the Netherlands and elsewhere. A number of changes have also occurred in drinking cups, the possible washing up of cups and waste disposal. The following is a summary (certainly not exhaustive) of certain changes:

- Improvement in trade dishwashers; reduction in water and energy consumption and application of other cleansers.
- Washing up decentrally in a small dishwasher or even individually instead of central washing-up.
- Vending machines with choice buttons (with or without disposable cup)
- Weight reduction of disposable polystyrene cups
- Various recycling options (in various products) for polystyrene
- Application of used treated polystyrene (sub-coal) as fuel in power plants
- Number of times a porcelain cup and saucer are used without washing up
- More frequent use of the disposable polystyrene cup
- Adjustments to the disposable polystyrene insert cup with reusable cup holder
- More frequent use of the disposable polystyrene insert cup

Because the question “What is better for the environment, drinking coffee out of a disposable or reusable cup?” still has a certain topicality, the Stichting Disposables Benelux [Benelux Disposables Foundation] has commissioned TNO to carry out a revised environmental comparison.

The objective of the investigation is to update the studies concerned [1] and [2] (inter alia the influence of the changes mentioned). This concerns the LCA methods applied, the assumptions adopted and the values of the various parameters used to make the various comparisons. In addition, the sensitivity of the LCA results will be evaluated for certain assumptions or parameter values.

The methods adopted for implementing the lifecycle assessment (LCA) are further described and explained in Chapter 2. The cup systems to be investigated are described in Chapter 3; properties and specific circumstances/characteristics are explained. The results of the environmental analyses undertaken are discussed in detail in Chapter 4. Chapter 5 further explains why certain sensitivity analyses were adopted. The results of these are similarly described. In addition, the dominant sensitivities are further examined. This is followed in Chapter 6 by aggregated environmental analysis results; this concerns both the results as described in Chapter 4 and those of the sensitivity analyses as stated in Chapter 5. Finally, the conclusions and recommendations follow in Chapter 7.

Part I;
in conformity with the ISO 14040 and ISO 14044 standards

2. Lifecycle coffee cups

2.1 Goal and scope of the study

The goal of this comparative LCA is to update the results of the environmental comparison of drinking systems in the studies mentioned above [1] and [2]. This updating concerns the LCA methods and assumptions applied and the values of the various parameters included in the comparisons made. In addition, the sensitivity of the LCA results will be tested for important assumptions and parameter values. The study is directed at a situation that is representative of current Western Europe.

The intended audience consists of those making the decisions of which drinking system will be used within a company or institute, the users of drinking systems in office or factory environments and those who want to influence the environmental burden of office and factory employees.

2.2 Functional unit

In order to compare systems with each other in an equivalent way, everything must be brought under the same denominator. This is done by defining the so-called functional unit that describes the function to be fulfilled by the systems in an unambiguous quantitative manner. The function is to distribute hot drinks from a drinks vending machine or dispenser in an office or factory environment. The functional unit belonging to this is as follows:

> The dispensing of 1000 units of hot drinks (tea/coffee/hot chocolate) from a vending machine or dispenser in an office or factory environment.

Based on an employees 220 working days a year, he will have to drink slightly more than 4.5 cups a day on average in order to achieve these 1000 units. This consumption quantity is based on a small sample within the TNO location at Apeldoorn and at the ‘Huis der Provincie’ (provincial headquarters) of the Province of Gelderland. This figure is slightly lower than the citation by Autobar Holland [3] of 6 items consumed per employee per day. The functional unit is so dimensioned that even with reusable systems, clearly evident quantities of material (porcelain/earthenware) are used.

The TAUW studies [2] took one production unit (cup and saucer, cup) as the functional unit. This is not so much a functional unit as an arithmetical unit. Based on the results of the arithmetical units, transition points[1] were established between disposable and reusable systems. This study is based on an approach from the function of dispensing hot drinks and therefore not of dispensing cold drinks.

The most commonly used disposable vending cups have a filled volume of 150 or 180 ml. When choosing the precise filling of the systems, the filling volume of 180 ml is used as the benchmark.

2.3 Drinking systems

The choice of systems made in the study is such that they effectively cover the current Western European situation generally. Systems have therefore been chosen where use is made of a reusable facility and those where use is made of a disposable cup to vend or dispense drinks. The reusable facility may be a porcelain cup and saucer or an earthenware mug. The product system is reproduced in diagram form in Figure 1. The diagram for the disposable systems appears in Figure 2. The same numbering of life phases as in Figure 1 is used in this case. The digits in these figures indicate the various life phases. The numbering is also used when presenting the results (especially with the use of diagrams) (see Chapters 4 and 5).

[1] A transition point is a point where a system will start to perform better than that with which it is compared. A variable, e.g. the number of uses after which the porcelain cup and saucer are cleaned, is varied here. The comparison is made per environmental effect category (e.g. greenhouse effect or human toxicity). There may well be no transition point between two systems for a specific comparison because the one system always performs better than the other.

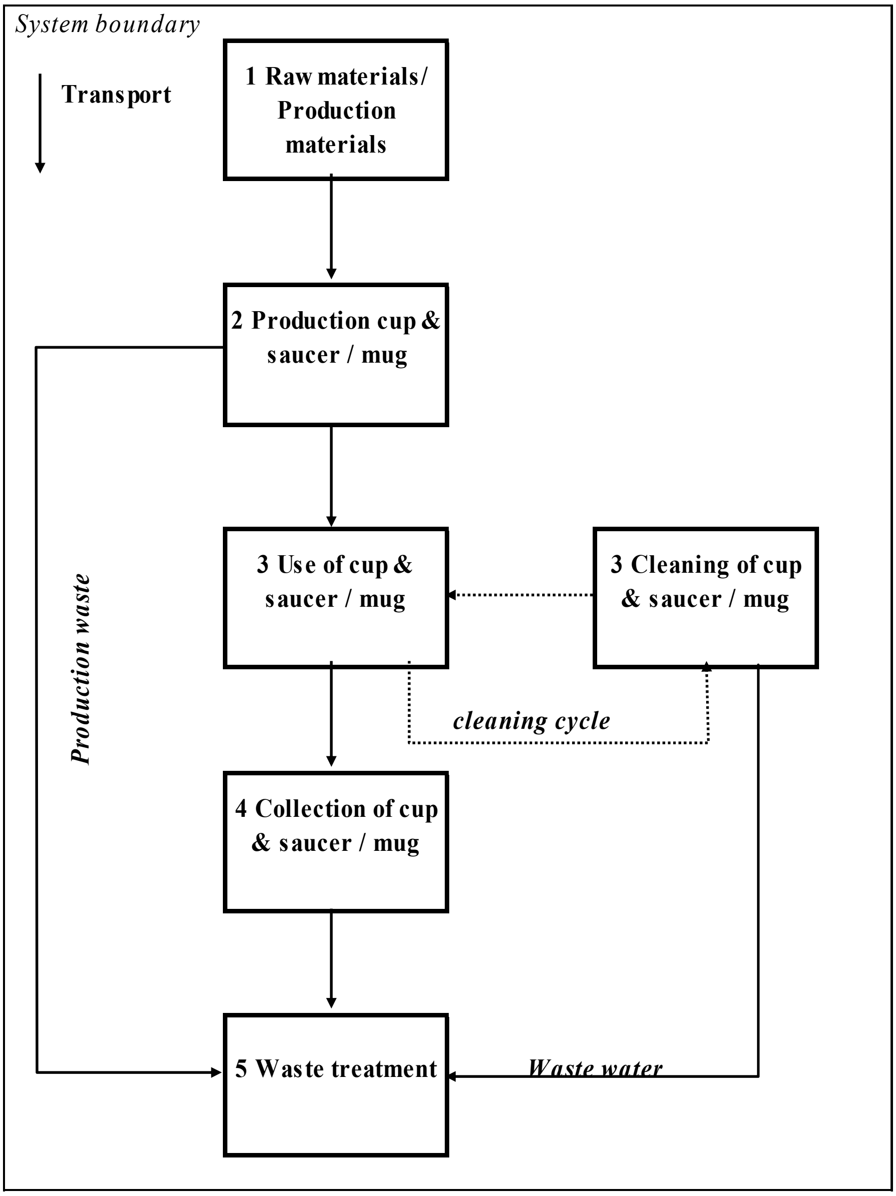

Figure 1 *Diagram showing the use of reusable systems (porcelain cup and saucer, earthenware mug).*

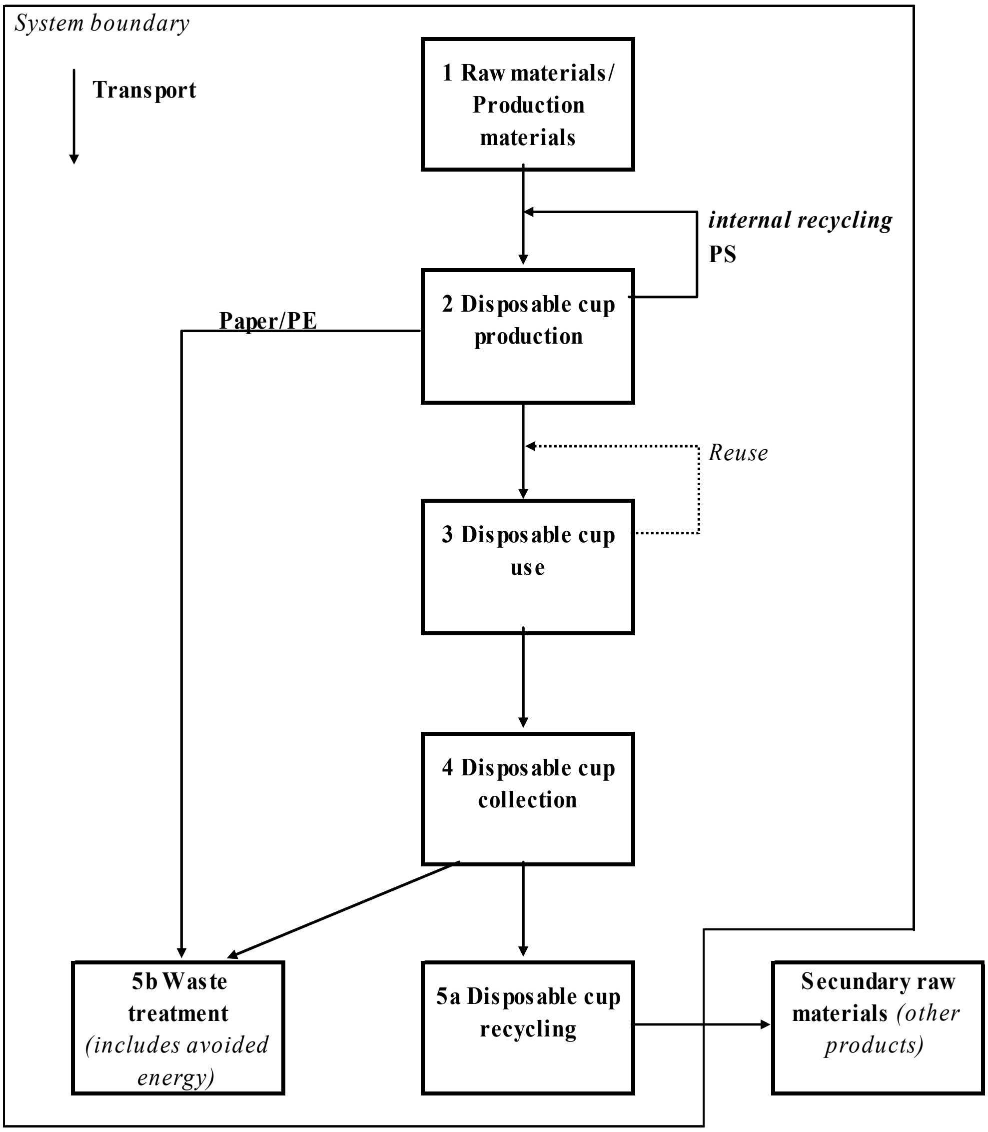

Figure 2 Diagram showing the use of disposable systems. The possible more frequent use of cups is indicated by a dotted line.

2.4 System limits

The system limits are further described for a proper insight into the environmental effects of using coffee cups. This makes it clear what is included in the environmental analysis and what is not. Figure 1 and Figure 2 show the system limit as being the edges of the diagram.

Excluded from the analysis
- Transport packaging for disposable and reusable systems
- Apparatus/dispensers for preparing coffee/tea
- Production and preparation of coffee/tea
- Apparatus for cleaning the cup
- Part of the building where the coffee vending machine is located, the kitchen, etc.
- Infrastructure (roads, means of transport, means of production)

The mass of the transport packaging compared to that of the cups is estimated to be below 10% and these materials are fully recycled. For that reason, and the environmental impact is expected to be limited, transport packaging has been excluded.

Included in the analysis
- Production of raw materials
- Production of disposable and reusable systems
- Use of the systems (with cleaning of the cup and saucer/mug where applicable)
- Collection of used disposable or reusable systems (including specific collection transport)
- Waste processing and recycling
- Transport of materials and of the cup to the user and transport to recycling and waste processing.

When cleaning a reusable cup, treatment of the wastewater in a sewage purification plant (RWZI) is also included. The relevant data appear in Annex 3.

The Dutch market for drinking systems forms part of a European market; raw materials come from Europe and also the reusable cup and saucers, mugs and disposable cups are partly imported. Therefore Europe was chosen for the scope of the study, which implies that, where necessary and possible, LCI data that are valid for Western Europe and the rest of Europe are preferentially used. The Dutch situation has been chosen as a reference for waste treatment.

2.5 Environmental effect categories

The study uses the CML2 method [7] accepted in the Netherlands and beyond in order to translate the product system inputs and outputs into environmental effects. The basic effect categories are:
- Abiotic mineral resources depletion potential (ADP)
- Global warming potential (GWP)
- Ozone depletion potential (ODP)
- Human toxicity potential (HTP)
- Fresh water aquatic eco-toxicity potential (FAETP)

– Marine aquatic eco-toxicity potential (MAETP)
– Terrestrial eco-toxicity potential (TETP)
– Photochemical ozone creation potential (POCP)
– Eutrophication potential (EP)
– Acidification potential (AP)

The effect categories adopted for this study are further described in Annex 2. Annex 2 also enlarges on the ecotoxicity of metals that may require special attention when interpreting the LCA results.

2.6 Normalisation

After characterising the systems by allocating the absolute scores for the individual effect categories, the next step in interpreting the LCA results is to normalise the scores. This normalisation is achieved by relating the absolute scores to those for the annual contributions to the effect categories within a reference area. Western Europe has been selected for this study, with 1995 as the reference year used [7]. By normalisation the year appears as the dimension. The normalisation data used appear in Table 1.

Table 1 Normalisation factors for the environmental effect categories for Western Europe in 1995 [7].

Environmental effect category	Abbreviation	Value (year/kg)[1]
Abiotic mineral resources depletion potential	ADP	6.74E-11
Global warming potential	GWP	2.08E-13
Ozone depletion potential	ODP	1.20E-08
Human toxicity potential	HTP	1.32E-13
Fresh water aquatic eco-toxicity potential	FAETP	1.98E-12
Marine aquatic eco-toxicity potential	MAETP	8.81E-15
Terrestrial eco-toxicity potential	TETP	2.12E-11
Photochemical ozone creation potential	POCP	1.21E-10
Acidification potential	AP	3.66E-11
Eutrophication potential	EP	8.02E-11

1 The characterised effect (in kg) is in fact divided by the reference emission per year (kg eq./year) for normalisation. The normalisation factor by which the characterised effect is multiplied therefore, using year/kg as the unit.

2.7 Allocation

Allocation is an influential activity when undertaking an LCA. Allocation is the correct attribution of inputs and outputs to a particular process. Production processes may generate several products where a choice must be made as to which inputs and emissions must be assigned to a specific product. Allocation has already been made for many of the processes in LCI databases (see e.g. [15]).

Allocation plays a very important role in assigning the favourable effects of recycling. The standard ISO 14041 which concerns allocation amongst other aspects indicates as possibilities:
– Physical properties (mass, combustion value, etc.)
– Economic value (e.g. value of the secondary raw material compared with the value of the primary raw material)
– The number of times that a material can be recycled (downcycling).

Because this study uses product systems within the Western European economy, preference has been given to economic allocation.

Allocation is applied for the following processes:
– Recycling of used polystyrene: allocation of avoided polystyrene production based on the ratio of secondary PS price to primary PS price.
– Recycling of cardboard punch wastes: based on quality reduction (20% per cycle) of the fibre [11].
– Energy generation by incinerating waste. Incineration of materials in an MSWI (waste to energy incineration plant) can produce energy. This energy is partly applied to generate electricity and to distribute heat. This avoids the generation of electricity elsewhere in the grid (UCTE production mix) and the generation of heat with natural gas in an industrial boiler is avoided. Allocation is made on the basis of the lowest material-specific combustion value. In addition, the use of auxiliaries in the MSWI is allocated in relation to the material (see VLCA database for details [21]).

2.8 Data quality requirements

Data quality may be generally defined as “characteristics of data that bears on their ability to satisfy stated requirements”. In most LCAs, data describing many different types of technical systems are acquired. Depending on the purpose of the study, requirements are put on data quality and what type of data that can be used in the LCA. The requirements may concern both qualitative and quantitative aspects such as e.g. to what extent the data describes the studied technology, the precision of the data etc. The quality of any specific LCI-data set is therefore dependent on the context in which it is used. The quality of any given LCI-data set in a specific application may only be determined through a thorough knowledge of the system and of the data [22].

The data quality requirements address the following [27]:

a) time-related coverage: For this study the data should be representative for 2005. The data should be preferably not more than five years old;

b) geographical coverage: the data must be representative for Western Europe;
c) technology coverage: current technology used on the market;
d) representativeness: qualitative assessment of the degree to which the data set reflects the true population of interest (i.e. geographical coverage, time period and technology coverage);
e) sources of the data.

It may happen that not all data of a unit process can be collected. In this case the size of an expected flow may be set to zero or be calculated from similar processes.

2.9 Critical review

The study is intended to be used for a comparative assertion intended to be disclosed to the public; therefore ISO 14040 sets additional requirements. A main requirement is that a review panel consisting of interested parties shall conduct a critical review [28].

The critical review process shall ensure that:
- the methods used to carry out the LCA are consistent with this International Standard;
- the methods used to carry out the LCA are scientifically and technically valid;
- the data used are appropriate and reasonable in relation to the goal of the study;
- the interpretations reflect the limitations identified and the goal of the study, and
- the study report is transparent and consistent.

In case a critical review is carried out by interested parties, an external independent expert should be selected by the original study commissioner to act as chairperson of a review panel of at least three members. Based on the goal and scope of the study, the chairperson should select other independent qualified reviewers.
The review statement and review panel report, as well as comments of the expert and any responses to recommendations made by the expert or by the panel, shall be included in the LCA report.

The review panel for the study consisted of:
- Theo Geerken, VITO, Belgium (chairperson)
- Päivi Harju-Eloranta, Stora-Enso, Finland
- Kasturirangan Kannah, NOVA Innovene, UK
- Yannick. Leguern, BIO Intelligence Service, France

3. Description of drinking systems

3.1 Introduction

When describing drinking systems, use is made inter alia of the studies from the early nineties [1], [2] and the study of the collection and recycling of used polystyrene cups [4]. These data are supplemented with recent external information, measurements and estimates. Recent data have been used for the environmental effects of producing the materials and products (such as inter alia [15]).

3.2 Reusable systems

Two reusable systems are distinguished in the study. Firstly, the porcelain cup and saucer, which are washed in a central dishwasher in the works canteen after every use (the cup and saucer used are placed in a collecting basket next to the dispenser).

The second system is the reusable mug, which is the property of the employee himself and is washed up by him/her in a pantry/kitchen. The basic situation is that this is done after each use and that hot water is used from an electric kitchen boiler.

3.2.1 Reusable porcelain cup and saucer

Description of porcelain cup and saucer
The reusable cup and saucer are made of porcelain. Both Dutch and imported products appear on the Dutch market. On the basis of Table 3.4 from [1] imports amount to 85%. It is assumed that these imports come from Europe.

On the basis of the TAUW Study [1], own measurements and market information, the average weight is used of a porcelain saucer of 0.473 (± 0.056) kg. This is slightly above the 0.45 kg used in the TAUW study for 190 ml porcelain cups and saucers.

It is assumed that the reusable porcelain cup and saucer will last for an average of 3,000 drinking dispensed [1]. The consequence of this is that an average of 1/3 porcelain cups and saucers is required to constitute the functional unit.

Utilisation stage of porcelain cup and saucer
The porcelain cup and saucer used are placed in a collecting basket next to the dispenser and washed in a central dishwasher in the works canteen. In accordance with the basic scenario, the porcelain cup and saucer are deposited in the collecting

basket for washing up after one dispensing. It is a fact that many users use the porcelain cup and saucer for more than one consumption. Because the number of usages before cleaning will play an important role in environmental burden, the effect of this is further determined in a sensitivity analysis.

Use of a dishwasher is defined in the TAUW study [1], where 0.68 l of water and 0.91 grams of detergent were used per kg of porcelain. More recent data appear in the literature for the use of a professional continuous dishwasher (see Figure 3). The study “Reusable versus Disposable” [5] has been used as a basis for this. The details appear in Annex 3. It has been found that the consumption of energy and water may differ widely per unit [13]. The value used of 0.0184 kWh per porcelain cup and saucer (including drying) is close to the value measured by Fresenius [13] of 0.015 kWh for the same type of professional dishwasher. Water consumption at 0.126 l per porcelain cup and saucer is clearly below the measure value of 1.1 litres, but is nonetheless within the manufacturer's citation [13]. A recent, but confidential, LCA of the use of a porcelain cup and saucer in an office environment shows that the use of water, electricity and detergent estimated here is on the low side [14].

Figure 3 Example of a trade dishwasher for an industrial kitchen [16].

The detergent data were obtained through the Dutch Association of Soap Manufacturers (NVZ) [12] and are included in the inventory (see Annex 2). Unlike the TAUW study [1], sewage purification plant use is also included in the product system.

Waste processing
The porcelain cup and saucer used are disposed of with non-process-related waste at the end of the life cycle. It is assumed that porcelain behaves as an inert material in the MSWI.

Environmental data
Table 2 provides an overview of the sources of the environmental data.

Table 2 Environmental data for the application of the porcelain cup and saucer.

Item	Process; source	Comment
Porcelain production	Sanitary porcelain from regional store; [15]	Most recent and most comparative process; original makes use of clay and kaolin mix but 100% kaolin in this study.
Detergent	See annex 3; [12], [15]	Energy consumption mixing not included. Composition via [12]
Electricity	Electricity Low Voltage use in UCTE [15]	Most recent Western European data and average technology. Representative for 2000
Sewage purification plant (RWZI)	Treatment, sewage, to wastewater treatment, class 2/CH; [15]	Swiss sewage purification plant (RWZI). Infrastructure excluded.
Waste processing	TNO waste incineration model [21]	Modern (1995-2000) waste incineration process, representative for process with energy recovery.

The production of (sanitary) porcelain may not be fully representative for the cup and saucer. However the process is adapted to 100% kaolin. In case this process is very significant for the overall results it will be subject of further evaluation.

3.2.2 Reusable earthenware mug

Description of earthenware mug
The reusable mug is made of porcelain or earthenware. A ratio of 10% porcelain to 90% earthenware is adopted. Compared with porcelain, earthenware uses less kaolin as raw material and is fired at lower temperatures. The result is lower environmental burden.

Use stage
The earthenware mug is washed by hand in hot water from an electrical kitchen boiler after every use to ensure that the hygienic circumstances are comparable to the other systems. On the basis of daily use, including stand-by losses, of electricity (1.63 kWh) from a kitchen boiler and the estimated water consumption from boilers of this kind in an office situation (15 l), electricity consumption is estimated at 0.109 $kWh.l^{-1}$ [24], [25]. The washing up of an earthenware mug is estimated to consume 0.4 l each time.

The base case was questioned for its representativity in the reviewing process for its high cleaning frequency. The influence on environmental effects of another cleaning frequency or type of cleaning of the earthenware mug, already determined in a sensitivity analysis (see 5.3, 5.5, 6.8.2 and 6.8.4), will therefore get extra attention in the evaluation of the results.

Waste processing
The earthenware mug used is removed with the non-process-related waste at the end of the lifecycle. It is assumed that the earthenware will behave as an inert material in the MSWI.

Environmental data
Table 3 provides an overview of the sources for the environmental data.

Table 3 Environmental data for applying the earthenware mug.

Item	Process; source	Comment
Earthenware and porcelain production	Sanitary porcelain from regional store; [15]	90% consists of earthenware. Most recent and comparative process. Raw material composition is adapted to stoneware. For earthenware, 80% of energy use of porcelain.
Detergent	See annex 3; [12], [15]	Energy use mixing and possible process emissions excluded. Composition based on [12].
Electricity	Electricity Low Voltage use in UCTE [15]	Most recent Western European data and average technology. Representative for 2000
Sewage purification plant (RWZI)	Treatment, sewage, to wastewater treatment, class 2/CH; [15]	Swiss sewage purification plant (RWZI). Infrastructure excluded.
Waste processing	TNO waste incineration model [21]	Modern (1995-2000) waste incineration process, representative for process with energy recovery.

The production of (sanitary) porcelain may not be fully representative for the earthenware mug. However the raw material composition and energy use are adapted to stoneware. In case this process is very significant for the overall results it will be subject of further evaluation.

3.2.3 Transport distances and transport means for reusable systems

Transport do take place in the reusable systems from the beginning of the life cycle up to the end-of-life stage. The transport distances and means that are not already included in the Ecoinvent processes, are given in Table 4 and Table 5.

Table 4 Transport distances and transport means between the several life cycle stages for the porcelain cup and saucer not already included in the (Ecoinvent) LCI data.

From	To	Distance (km)	Return	Transport means
Raw materials (kaolin)	Production cup	760	N	barge
Raw materials (kaolin)	Production cup	47	N	lorry 32t
Raw materials (feldspar)	Production cup	120	N	lorry 32t
Raw materials (feldspar)	Production cup	1600	N	coaster
Raw materials (quartz)	Production cup	25	Y	lorry 32t
Raw materials (gypsum)	Production cup	600	N	lorry 32t
Production detergent	Use cup	150	Y	lorry 16t
Production cup	Waste treatment	50	N	lorry 16t
Production cup	Use cup	300	N	lorry 16t
Use cup	Waste treatment	100	Y	lorry 16t

Table 5 Transport distances and transport means between the several life cycle stages for the earthenware mug not already included in the (Ecoinvent) LCI data.

From	To	Distance (km)	Return	Transport means
Raw materials (kaolin/clay)	Production cup	760	N	barge
Raw materials (kaolin/clay)	Production cup	47	N	lorry 32t
Raw materials (feldspar)	Production cup	120	N	lorry 32t
Raw materials (feldspar)	Production cup	1600	N	coaster
Raw materials (quartz)	Production cup	25	Y	lorry 32t
Raw materials (gypsum)	Production cup	600	N	lorry 32t
Production cup	Waste treatment	50	N	lorry 16t
Production cup	Use cup	300	N	lorry 16t
Use cup	Waste treatment	100	Y	lorry 16t

3.3 Single use systems

3.3.1 Disposable polystyrene cup

The polystyrene vending cups on the Dutch market generally have a volume (filled) of 150 or 180 ml. In this study the calculations are carried out with the 180 ml volume.

Description of the disposable polystyrene cup
The TAUW study [1] was based on a cup weight of 4.1 grams, while on the basis of the data from the Stichting Disposables Benelux, the TNO study [4] used a cup weight of 4.0 grams. The range for polystyrene vending cups is between 3.8 and

4.5 grams. The cup weight of 4.0 grams will be used as a basis for the study, corresponding with the volume of 180 ml.

Figure 4 Polystyrene vending cup.

White polystyrene cups contain 1-2% colouring masterbatch. For this study, 2% titanium oxide is assumed. The polystyrene used is 60% General Purpose PS (GPPS) and 40% High Impact PS (HIPS) [23]. The cups are made from PS sheet through thermoforming. Production of the sheet and of the cups releases 0.54 kg of waste per kg of cups (see Table 6) recycled internally or externally. Internal recycling is assumed for this study, because this is the most frequent method in cup production (so-called in-line production).

Collection of used polystyrene cups
After use, polystyrene cups enter a collecting PE bag or a cardboard collecting box. The contamination percentage for the collected cups is high and the cups contain an average of 23.7% contamination in the form of drinking residues, cigarette ends and other waste [4].

The PE bags and/or boxes with used polystyrene cups are collected in a delivery van from firms affiliated to Stichting Disposables Benelux and taken to a storage point. Here, the boxes and PE bags are stored in containers and when two containers are full, they are transported to a pre-processor. This pre-processor removes the boxes and presses the polystyrene cups (and bags) into bales. The bales then proceed to the plastic recycler [4] for further processing.

Recycling and waste processing
The recycler applies a wet process for processing the used cups [4]. The polystyrene cups are processed together with material from flower auctions, such as PS plant trays. The wet process is adopted because the basic products are contaminated. A closed water circuit limits water consumption.

The separating and cleaning process applied passes the following stages:
1. removal of bale binding wires
2. breaking up bales and visual inspection
3. conveyor belt

4. reducing cup volume
5. sieving reduced material
6. washing of the sieved material
7. wet grinding
8. separation by float/sink separation
9. separation by hydrocyclone
10. mechanical drying of the plastic fractions.

The iron released during stage 1 is removed to a scrap yard. The small quantity of iron processed is excluded from the calculations. The polystyrene cups leave stage 5 together with other plastic products (including PE). This renders separation of the various plastics necessary, which is done during stages 8 and 9.

On the basis of data provided by Stichting Disposables Benelux, it is calculated that 16% contamination and humidity of the gross quantity of polystyrene cups [4] are released during recycling. Of this 16%, half is incinerated and the other half discharged into the sewer. It is assumed that the environmental effects of this waste processing are negligible.

Environmental data

Table 6 provides an overview of the sources for the environmental data.

Table 6 Environmental data for the application of polystyrene vending cups.

Item	Process; source	Comment
PS production	Polystyrene, GPPS[1], at plant; HIPS[1] and Titanium dioxide, production mix, at plant [15]	2% TiO_2 as white colouring masterbatch. Representative for Western Europe, average technology and most recent data.
Cup production	Extrusion, plastic film and thermoforming [15]; energy consumption from production cup: 0.9322 kWh/kg cup [20]	The production of 1 kg cups creates peripheral and punching losses [23]. These losses are recycled internally in the in-line system. Thermoforming in the in-line system occurs immediately after extrusion; this obviates heating the foil once again. Representative for current modern technology in Western Europe
Collection	By the Stichting Disposables Benelux system [4]	Specific Dutch current collection system.
Waste processing	TNO waste incineration model [21]	Modern (1995-2000) waste incineration process, representative for process with energy recovery.

1 These processes are based on data from Plastics Europe [36].

3.3.2 Disposable polystyrene insert cup

This cup is new compared with the systems analysed in the TAUW study [1].

Figure 5 Polystyrene insert cup and cup holder.

Description of the disposable polystyrene insert cup
The disposable polystyrene insert cup system consists of a disposable insert cup and a reusable cup holder. The insert cup uses less polystyrene per filling volume because it derives its rigidity from the cup holder. The cup holder is also usually made of polystyrene.
The polystyrene insert cup weighs 2.7 grams for a volume of 180 ml and the cup holder weighs 35.3 grams. These values will be used in the study. The impact of a lower mass for the polystyrene insert cup will be determined in a sensitivity analysis. It is assumed that the cup holder will last for an average of 1,000 consumptions.

Collection of disposable polystyrene insert cups
The polystyrene insert cup is collected by the Stichting Disposables Benelux system described in 3.3.1. The cup holder accompanies the non-process-related industrial waste at the end of its life cycle.

Recycling and waste process
See 3.3.1.

Environmental data

Table 7 provides an overview of the sources for the environmental data.

Table 7 Environmental data for the application of the PS insert cup and cup holder.

Item	Process; source	Comment
PS production	Polystyrene, general purpose, GPPS[1], at plant, HIPS[1],and Titanium dioxide, production mix, at plant [15].	2% TiO_2 as white colouring masterbatch. Representative for Western Europe, average technology and most recent data.
Insert cup production	Extrusion, plastic film and thermoforming [15]. Energy consumption from insert cup production: 0.9322 kWh/kg insert cup [20]	The production of 1 kg insert cups creates peripheral and punching losses [23]. These losses are recycled internally in the in-line system. Thermoforming in the in-line system occurs immediately after extrusion; this obviates heating the foil once again. Representative for current modern technology in Western Europe, most recent data.
Cup holder production	Injection moulding; [15]	1.006 kg of PS is required for 1 kg of cup holders because of injection moulding losses.
Insert cup collection	By Stichting Disposables Benelux system [4]	Specific Dutch current collection system.
Waste processing	TNO waste incineration model [21]	Modern (1995-2000) waste incineration process, representative for process with energy recovery.

[1] These processes are based on data from Plastics Europe [36].

3.3.3 Disposable paper cup

The paper cup is probably the oldest system for vending cups. The market share is small compared with the plastic cup.

Figure 6 Paper drinking cup.

Description of the disposable paper cup
The paper cup is made from two pieces of cardboard, the bottom and the wall, which are joined water-tight (see Figure 7). The cardboard is lined on one or both sides with a layer of polyethylene (PE). The ratio of the cardboard with the PE coating is not fully known, but we know that for paper cups used for cold drinks ratios occur of 19:1 and 16:1 [5]. For the basic scenario, based on data from the StoraEnso Product Selector, a ratio is assumed of 17:1 (5.9% PE) for cardboard coated on one side [25]. StoraEnso recommends cardboard coated on both sides for cold drinks, this material containing an average of 10.1% PE. The outside of the cup is generally printed. As a representative weight for the 180 ml paper cup, 5.0 grams is assumed on the basis of [18], [19] and [20].

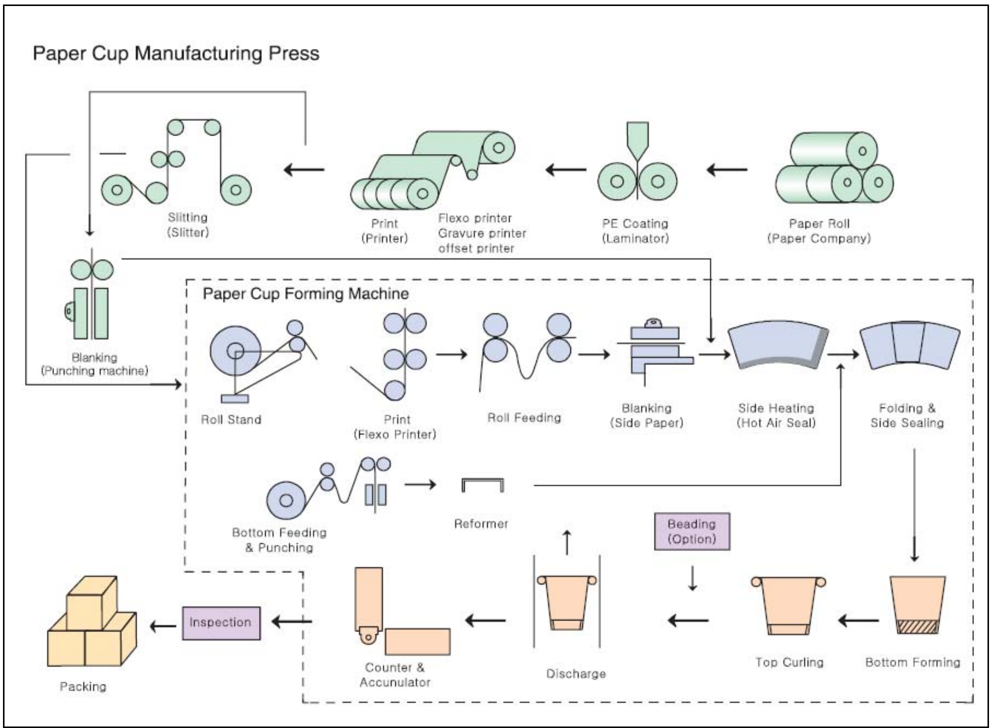

Figure 7 Production process for the paper drinking cup [17].

No specific LCI data are available for the production of paper drinking cups. Other studies in fact use “solid bleached board (SBB)” or craft paper [5] for the cardboard. The latter material appears an unlikely choice. For this study, use is made of liquid packaging board [15], which is used for food applications.

Collection and processing of the disposable paper cup
Until quite recently, the Stichting Disposables Benelux also collected paper cups. As quantities fell, it stopped this activity. The paper cups used now proceed to waste incineration (MSWI).

Environmental data

Table 8 provides an overview of the sources for the environmental data.

Table 8 Environmental data for the application of PE-coated paper cups.

Item	Process; source	Comment
PE coated cardboard production	Liquid packaging board, at plant and polyethylene granulate, at plant [15]	93.3% LPB, 6.7% PE
Cup production	Production of liquid packaging board containers, at plant [15]	Based on production of drinking board. 1 kg of cups requires 1.27 kg board because of punching and start-up losses. These losses are externally recycled. The energy consumption is based on measurement at one cup manufacturer [20] and on energy consumption for production of liquid packaging board containers, at plant [15]. The value used for the latter process is 150%.
Pre-consumer cardboard recycling (Punching and start-up losses)	Recycling process: Board, recycling, de-inking; avoided product: Sulphate pulp, unbleached [15]	Quality loss (80% of original quality) fibre is processed in avoided product.
Waste processing	TNO waste incineration model TNO [21]	Modern (1995-2000) waste incineration process, representative for process with energy recovery.

3.3.4 Transport distances and transport means for single use systems

In a number of the LCI (Ecoinvent) data used transport has already been included. However, for a number of transports between life cycle stages these transport data were not available or had to be changed specific to the study. The transport data are shown in the following two tables (Table 9 and Table 10).

Table 9 Transport distances and transport means between the several life cycle stages for the polystyrene (insert) cup not already included in the (Ecoinvent) LCI data.

From	To	Distance (km)	Return	Transport means
Raw materials (PS)	Production cup	300	N	lorry 32t
Production cup	Use cup	150	N	lorry 16t
Use cup	Transfer (collection)	216	N	van <3.5t
	Pre-treatment	210	N	lorry 16t
	Recycling	200	Y	lorry 16t
Pre-treatment (boxes)	Recycling	150	N	lorry 16t

Table 10 Transport distances and transport means between the several life cycle stages for the paper cup not already included in the (Ecoinvent) LCI data.

From	To	Distance (km)	Return	Transport means
Raw materials	Production paper	298	N	lorry 32t
Raw materials	Production paper	166	N	by rail
Production paper	Production cup	100	N	lorry 32t
Production paper	Production cup	186	N	by rail
Production cup	Recycling	150	N	lorry 16t
Production cup	Use cup	150	N	lorry 16t
Use cup	Recycling	150	N	lorry 16t
Use cup	Waste treatment	100	Y	lorry 16t

3.4 Evaluation of data quality

The obtained LCI data for the reusable and single use systems will be evaluated using the data quality requirements set in section 2.8 “Data quality requirements”. The data for the background systems like electricity delivery, heat generation and transport are from the ecoinvent database [15] and cover the processes in Western Europe in 2000. They were the most recent and most representative data available at the time of the study.
The weights of all of the drinking systems have been based on an average for the most recent systems in the Dutch situation. As the Dutch market for these systems is based on inland and European production it covers the current situation for Western Europe. The production processes have been based on recent industry specific data (PS cup and PS insert cup) or on comparable processes from the ecoinvent database (porcelain cup and saucer, earthenware mug and paper cup). The energy consumption in the use stage of the reusable systems is based on data of before 2000. The uncertainty in these data will be covered by a sensitivity analysis.
Data on the actual use in practice of each of the drinking systems was estimated as measured values were unavailable. This creates uncertainty in the LCA results; therefore sensitivity analyses are executed to estimate the impact of this uncertainty.

4. Environmental effects of using drinking systems

4.1 Introduction

When discussing the results of the assessment of effects, it is important to know whether a process makes a **significant contribution** to an effects category, or not. ISO provides no precise guidelines on this point, but a contribution of 20% or over may be adopted as a rule of thumb. Another point is whether a contribution can be regarded as negligible. ISO 14043 classifies the degree of importance for contributions to the LCI in terms of percentage additions. The criteria are:
- A: Most important, significant influence, contribution > 50%
- B: Very important, relevant influence, 25% < contribution ≤ 50%
- C: Relatively important, some influence, 10% < contribution ≤ 25%
- D: Hardly important, slight influence, 2.5% < contribution ≤ 10%
- E: Unimportant, negligible influence, contribution < 2.5%

This breakdown will be adopted when considering the results.

4.2 Reusable porcelain cup and saucer

The environmental profile is dominated by the user stage, the contribution varying between 90 and 100% depending on which effect category, see Figure 8. The absolute values per effect category appear in Table 11. The production of the porcelain has a negligible to slight influence on the categories ADP, GWP, and ODP. The other lifecycle phases have a negligible influence.

Table 11 Environmental profile of the porcelain cup and saucer.

Category	Unit	Total
ADP	kg Sb eq.	8.15E-02
GWP	kg CO_2 eq.	1.18E+01
ODP	kg CFC-11 eq.	5.42E-07
HTP	kg 1.4-DB eq.	4.36E+00
FAETP	kg 1.4-DB eq.	1.64E+00
MAETP	kg 1.4-DB eq.	8.68E+03
TETP	kg 1.4-DB eq.	1.92E-01
POCP	kg C_2H_2	3.52E-03
AP	kg SO_2 eq.	7.34E-02
EP	kg PO_4^{3-} eq.	1.16E-02

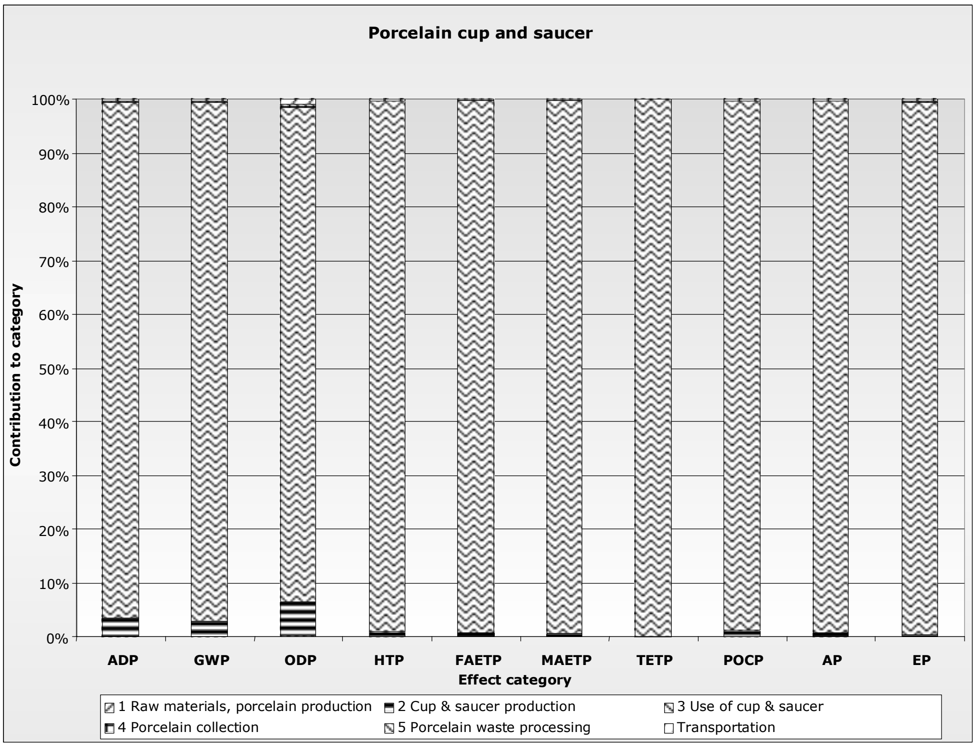

Figure 8 Environmental profile of the porcelain cup and saucer.

A more detailed explanation will now be given for the user stage per effect category (see Table 12).

Table 12 Most important contributions/emissions for the most important life stage of the reusable porcelain cup and saucer to the effect categories.

Category	3[1] Use of porcelain cup and saucer
ADP	Coal and natural gas use
GWP	CO_2 emission on generating electricity
ODP	CFC-10 and Halon-1301 emissions on extracting fuels.
HTP	Selenium emission on burning solid fossil fuels
FAETP	Vanadium emission on burning mineral oil
MAETP	Emission of hydrogen fluoride on burning solid fossil fuels.
TETP	Emission of vanadium and mercury on burning solid fossil fuels.
POCP	Emission of carbon monoxide, methane and pentane on burning fossil fuels.
AP	Emission of sulphur and nitrogen oxides on burning solid fossil fuels.
EP	Emission of nitrogen oxides on burning fuels, nitrate and phosphate in sewage effluent.

1 The digit 3 refers to the third life stage (see Figure 1).

For ADP (exhaustion of raw materials) 87% of the impact is due to the consumption of electricity in the dishwasher. This chiefly concerns the exhaustion of coal and gas.

The electricity consumption also makes the greatest contribution to the greenhouse effect (GWP). The emission of CO_2 on generating electricity from fossil fuels is the most important cause. Emissions of halons and CFCs which in particular are released on the production of mineral oil and electricity consumption, are the most important cause for the high ODP score for the use of the dishwasher. The use of the dishwasher consequently contributes 92% to the total score for ODP.

Because of the significant influence of the contribution that the dishwasher makes to the environmental profile, this will be considered further. The relative contribution of the various sub-processes to the use of the dishwasher is shown per effect category in Figure 9. Because, in addition, the uncertainty in the user and other data for the dishwasher is extensive, this will be the subject of a sensitivity analysis.

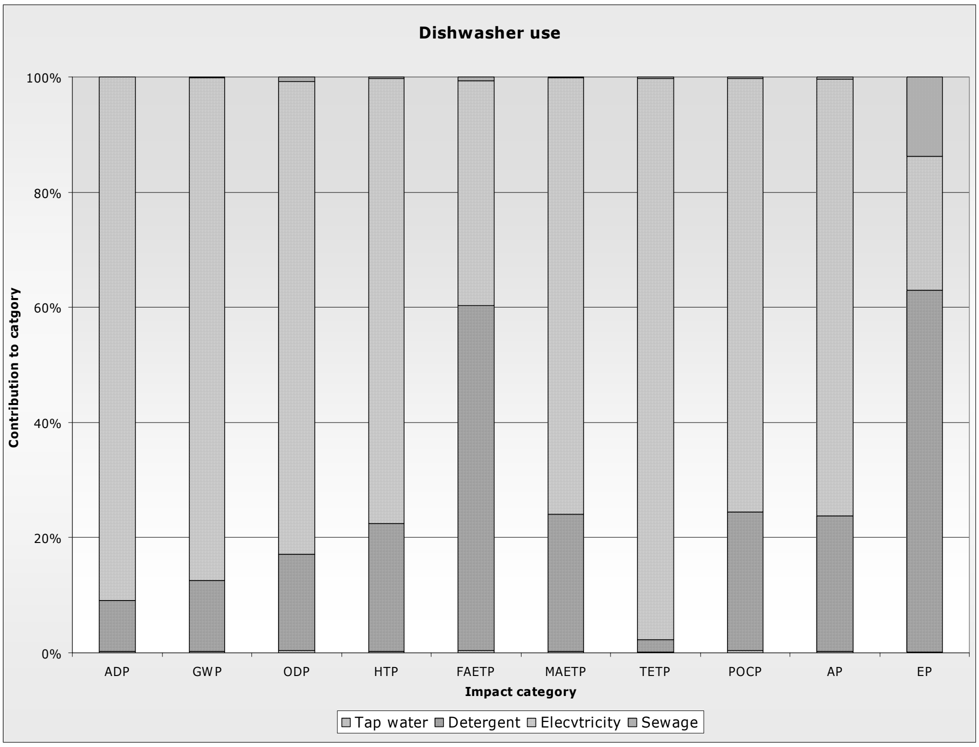

Figure 9 Environmental effects of using the dishwasher.

For the human toxicity category (HTP) the use of electricity is the most important process (emission of vanadium) and the use of detergents is a very important process. For electricity consumption, the emission of arsenic is the most important. The emission of vanadium to surface water during detergent production forms the most important contribution to the category of freshwater ecotoxicity (FAETP). The use of detergents is the most important process with regard to the contribution to this effect category; the use of electricity is very important.

The use of electricity is most important for the marine ecotoxicity category (MAETP); the use of detergents is now very important. The emission of hydrogen fluoride (HF) to the air is the most contributory emission to the MAETP category. The last ecotoxicity category is the terrestrial (TETP). The use of electricity is the most important sub-process on account of the vanadium and mercury emissions. The effect category photochemical oxidant formation (POCP) has use of detergents as the most important process and the use of electricity as a very important process. The emission of sulphur dioxide is the most contributing. For acidification (AP) the emission of sulphur dioxide is the significant influencing one. This emission occurs on production of electricity and of detergents. The last effect category is eutrophication (EP). The use of detergents is the most important; the use of electricity is very important and wastewater treatment in a sewage purification plant is relatively important. The emission of phosphate to water and nitrogen oxides to the air are the significant influencing ones.

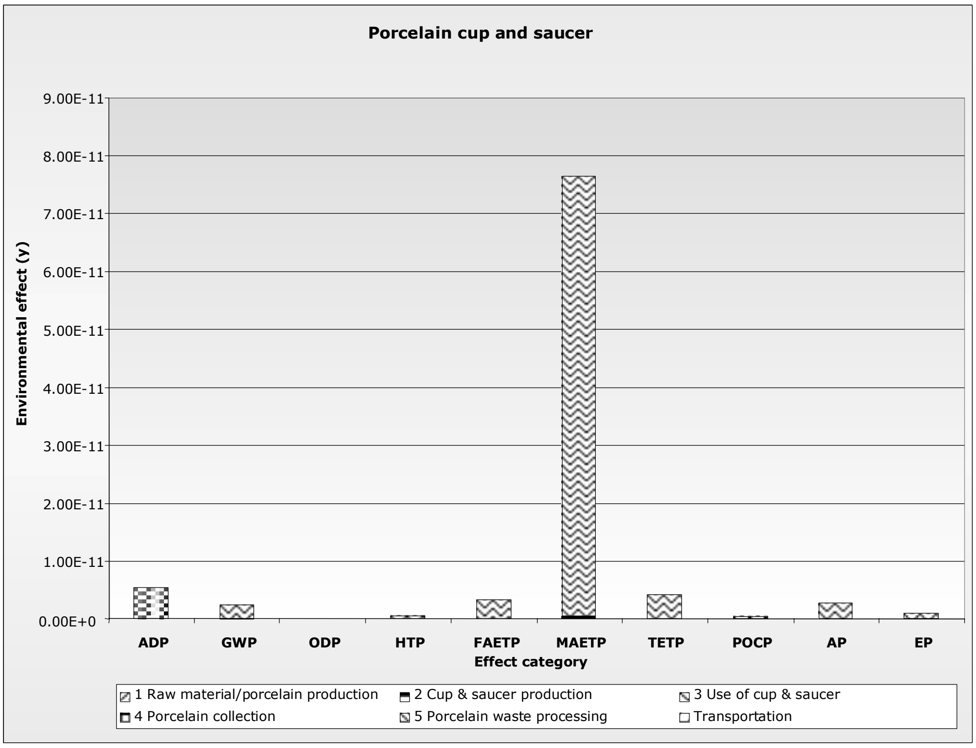

Figure 10 Normalised environmental profile for the porcelain cup and saucer.

When the scores for each category are related to the values that the total European emissions had in 1995 in the environmental profile, we obtain the normalised environmental profile. For the porcelain cup and saucer (Figure 10) it is clear that the environmental profile is dominated by the marine ecotoxicity (MAETP). This is due to the fact that the standardisation factor excludes the hydrogen fluoride emission.

4.3 Reusable earthenware mug

For the reusable earthenware/porcelain mug, the user stage is also the most important process. (See Figure 11). The production of the earthenware (of which 90% of mugs are made) and of the porcelain is negligible (contribution less than 2.5%). The production of the raw materials for earthenware and porcelain has a negligible effect on the environmental profile. This also applies to transportation within the system, to the collection of earthenware mugs at their end of life, and to waste incineration.

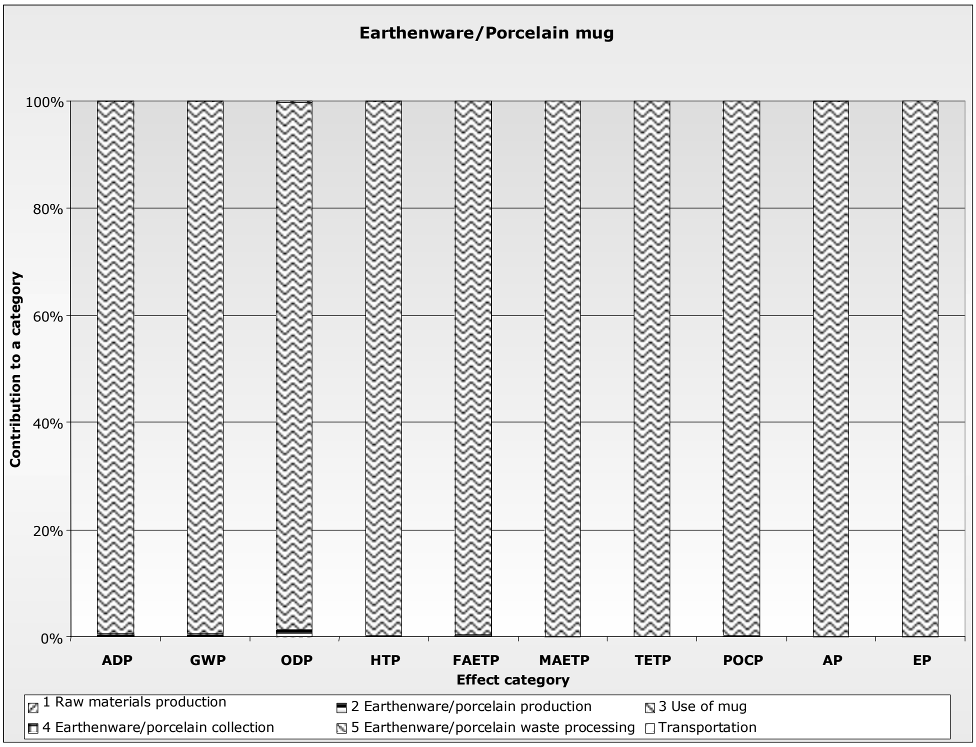

Figure 11 Environmental profile for reusable earthenware/porcelain mug.

Table 13 Environmental profile for the reusable earthenware/porcelain mug.

Category	Unit	Total
ADP	kg Sb eq.	1.71E-01
GWP	kg CO_2 eq.	2.38E+01
ODP	kg CFC-11 eq.	1.00E-06
HTP	kg 1.4-DB eq.	7.97E+00
FAETP	kg 1.4-DB eq.	1.56E+00
MAETP	kg 1.4-DB eq.	1.56E+04
TETP	kg 1.4-DB eq.	4.45E-01
POCP	kg C_2H_2	6.39E-03
AP	kg SO_2 eq.	1.32E-01
EP	kg PO_4^{3-} eq.	1.14E-02

The environmental effects of using the earthenware mug (after each use the mug is washed by hand in hot water from an electrical kitchen boiler) are virtually entirely the result of the use of electricity. The effects of the waste water proceeding to the sewage purification plant for purification has a negligible influence. An exception to this is the eutrophication effect to which the sewage purification plant contributes over 40% (see Table 14). Account must be taken here of the fact that the effects of the sewage purification plant are based on an average wastewater flow. The dirt burden when washing the earthenware mug will be below the average.

Table 14 Most important contributions/emissions of the very to most important life stages of the reusable earthenware/ porcelain mug to the effect categories.

Category	3[1] Use of earthenware mug
ADP	Coal and natural gas use
GWP	CO_2 emission on generating electricity
ODP	CFC-10 and Halon-1301 emissions on extracting fuels.
HTP	Selenium emission on burning solid fossil fuels
FAETP	Vanadium emission on burning mineral oil
MAETP	Emission of hydrogen fluoride on burning solid fossil fuels.
TETP	Emission of vanadium and mercury on burning solid fossil fuels.
POCP	Emission of carbon monoxide, methane and pentane on burning fossil fuels.
AP	Emission of sulphur and nitrogen oxides on burning solid fossil fuels.
EP	Emission of nitrogen oxides on burning fuels, nitrate and phosphate in sewage effluent.

1 The digit 3 refers to the third life stage (see Figure 1).

The standardisation of the characterised values (see Table 13) produces the normalised environmental profile (see Figure 12). As with the environmental profile for the porcelain cup and saucer (see Figure 10), the marine ecotoxicity dominates the picture, caused by the HF emissions during the application of solid fossil fuels.

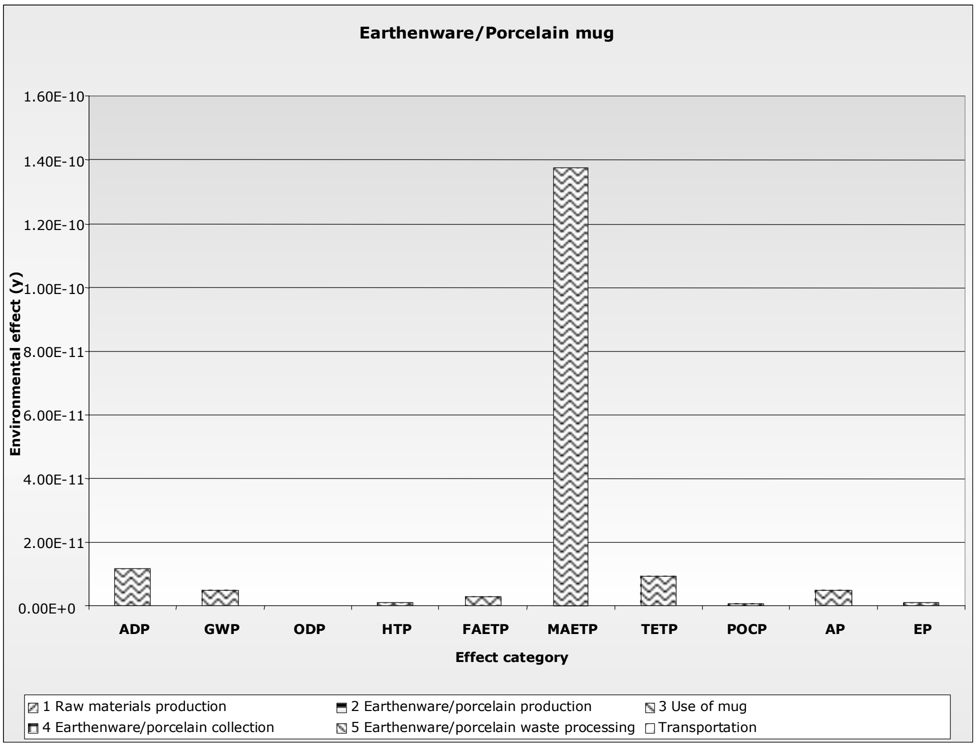

Figure 12 Normalised environmental profile for the reusable earthenware/ porcelain mug.

4.4 Disposable polystyrene cup

The environmental profile for the disposable polystyrene cup differs substantially from that for the reusable cups. Instead of use of the cup determining the environmental profile, it is now the production of the raw material, the production of the cup, the collection of the cup and the recycling that dominates the picture (see Figure 13).

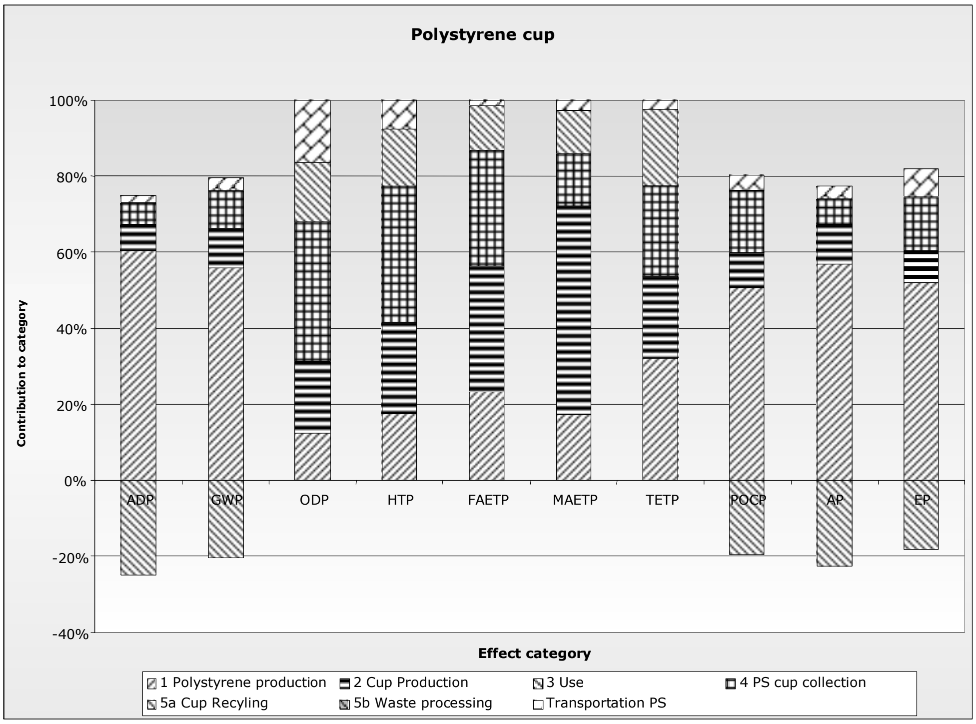

Figure 13 Environmental profile of the disposable polystyrene vending cup.

The production of polystyrene has a significant to relevant influence on the environmental effects, with the exception of the effects ODP, HTP, FAETP, MAETP and TETP. Producing the cup from polystyrene makes a very important and most important contribution to five effect categories (ODP, HTP, FAETP, MAETP, TETP). The collection of disposable polystyrene coffee cups makes relative contributions of 20% or over to the ODP, HTP, FAETP and TETP effects. Cup recycling makes a very important contribution to the environment regarding the effects ADP and AP.

Table 15 Environmental profile of the disposable polystyrene cup.

Category	Unit	Total
ADP	kg Sb eq.	1.36E-01
GWP	kg CO_2 eq.	1.29E+01
ODP	kg CFC-11 eq.	5.41E-07
HTP	kg 1.4-DB eq.	1.95E+00
FAETP	kg 1.4-DB eq.	6.38E-01
MAETP	kg 1.4-DB eq.	2.39E+03
TETP	kg 1.4-DB eq.	2.62E-02
POCP	kg C_2H_2	4.40E-03
AP	kg SO_2 eq.	6.91E-02
EP	kg PO_4^{3-} eq.	7.79E-03

Table 16 shows what the most important contributions are during very to most important life stages for the score of a particular effect category. The emissions of CO_2, dioxines, heavy metals, HF, SO_2 and NO_x as appearing in Table 16 all depend on the combustion of fossil fuels to generate energy.

Table 16 Important contributions/emissions of the very to most important life stages of the disposable polystyrene cup to the effect categories.

Category	1[1] Production PS	2[1] Cup Production	4[1] Cup collection	5a[1] Cup Recycling
ADP	Extracting natural gas and mineral oil			PS production avoided: (natural gas and mineral oil)
GWP	CO_2 emission			PS production avoided (CO_2)
ODP			Halon 1211 emission (gas extraction) and 1301 (oil extraction)	
HTP		Dioxine emission, Cr(VI)	Benzene emission, dioxins Cr(VI)	
FAETP		V, Zn and Be emission	Cu emission, dinoseb, Ni and V	
MAETP		HF emission		
TETP	V and Hg emission			
POCP	SO_2 emission	SO_2 emission	CO, NO_x and SO_2 emission	SO_2 emission
AP	SO_2 and NO_x emission			PS, SO_2 and NO_x production avoided
EP	NO_x emission			PS, SO_2 and NO_x production avoided

1 The digits refer to the life stages (see Figure 2).

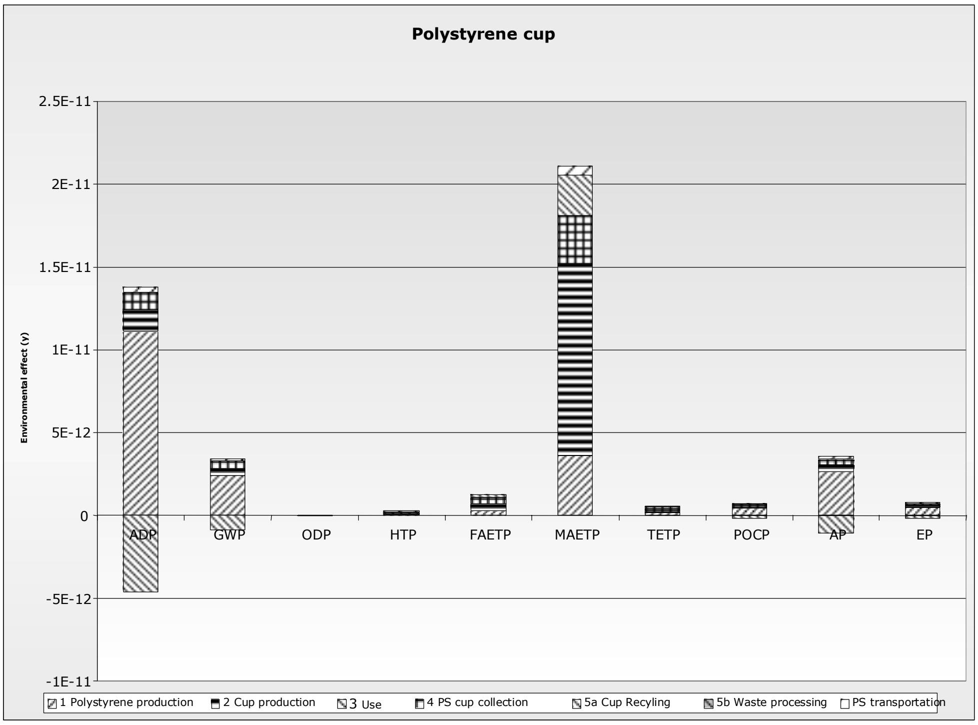

Figure 14 Normalised environmental profile for the polystyrene vending cup.

As already remarked in 4.3, marine ecotoxicity is the category with the highest score in the normalised environmental profile (Figure 14). The exhaustion of raw materials (ADP) is the second highest scoring effect category.

4.5 Disposable polystyrene insert cup

The environmental profile (see Figure 15) of the disposable polystyrene insert cup is logically analogous to that of the disposable polystyrene cup (see Figure 13). The production of the raw material and the insert cup determine the picture. The favourable effect (negative environmental impact) of recycling the plastic is now also evident. The net absolute values for each environmental effect category appear in Table 17.

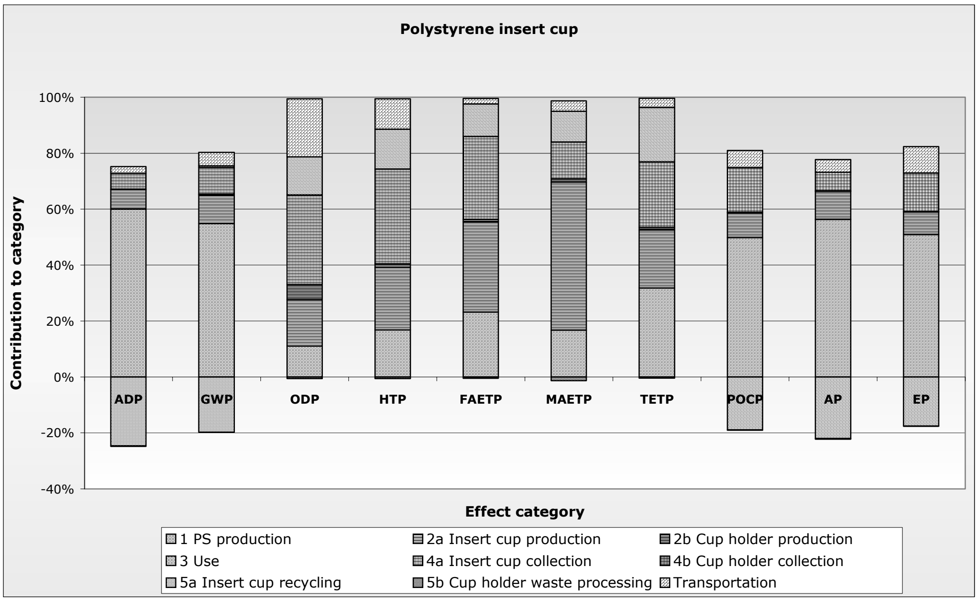

Figure 15 Environmental profile for the disposable polystyrene insert cup with reusable cup holder.

Table 17 Environmental profile for the disposable polystyrene insert cup with reusable cup holder.

Category	Unit	Total
ADP	kg Sb eq.	9.33E-02
GWP	kg CO_2 eq.	9.00E+00
ODP	kg CFC-11 eq.	4.06E-07
HTP	kg 1.4-DB eq.	1.37E+00
FAETP	kg 1.4-DB eq.	4.30E-01
MAETP	kg 1.4-DB eq.	1.61E+03
TETP	kg 1.4-DB eq.	1.78E-02
POCP	kg C_2H_2	3.07E-03
AP	kg SO_2 eq.	4.77E-02
EP	kg PO_4^{3-} eq.	5.47E-03

Polystyrene production is the most important to a very important process for the effect categories ADP, GWP, POCP, AP and EP. Production of the disposable PS insert cup is a very important to most important process for the five other effect categories. Recycling the collected disposable PS insert cups makes a very positive contribution to the environment for categories ADP and AP. Under ODP, the environment is affected through the use of fossil fuels earlier in the chain (production of PS, the insert cup and cup holder).
Table 18 shows the most important causes for the contribution to an effect category for the very to most important life stages.

Table 18 The most important contributions/emissions of very to most important life stages of the disposable plastic insert cup to the effect categories.

Category	1[1] PS production	2[1] Insert cup production	4[1] Insert cup collection	5a[1] Insert cup recycling
ADP	Extracting natural gas and mineral oil			PS production avoided: (natural gas and mineral oil)
GWP	CO_2 production			PS production avoided (CO_2)
ODP			Halon 1211 emission (gas extraction) and 1301 (oil extraction)	
HTP		Dioxine emission, Cr(VI)	Benzenes and doxine emission, Cr(VI)	
FAETP		V, Zn and Be emission	Cu emission, dinoseb, Ni and V	
MAETP		HF emission		
TETP	V and Hg emission			
POCP	SO_2 emission	SO_2 emission	CO, NO_x and SO_2 emission	SO_2 emission
AP	SO_2 and NO_x emission			PS, SO_2 and NO_x production avoided
EP	NO_x emission			PS, SO_2 and NO_x production avoided

1 The digits refer to the life stages (see Figure 2).

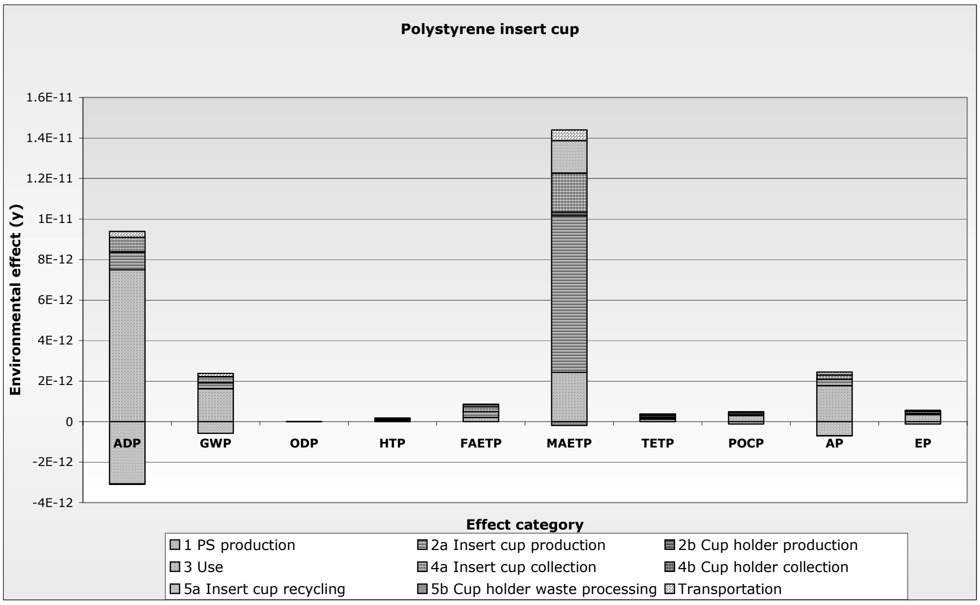

Figure 16 Normalised environmental profile for the disposable polystyrene insert cup.

It is clear from the normalised environmental profile (Figure 16) that MAETP again has the highest score, but the exhaustion of raw materials (ADP) also has a relatively high score compared with the other categories.

4.6 Disposable paper cup

In the environmental profile (Figure 17) for disposable paper cups coated with PE, the contribution of the production of the cardboard and the waste processing immediately hit the eye. Apart from ODP, production of the coated board is the most important to very important process with regard to the contribution(s) to the effect categories. For this category, the production of the cup is the most important process.

Waste processing of cardboard has a positive effect on the environment for all categories because the incineration of cardboard in the MSWI avoids the production of electricity and cardboard is a relatively clean fuel.

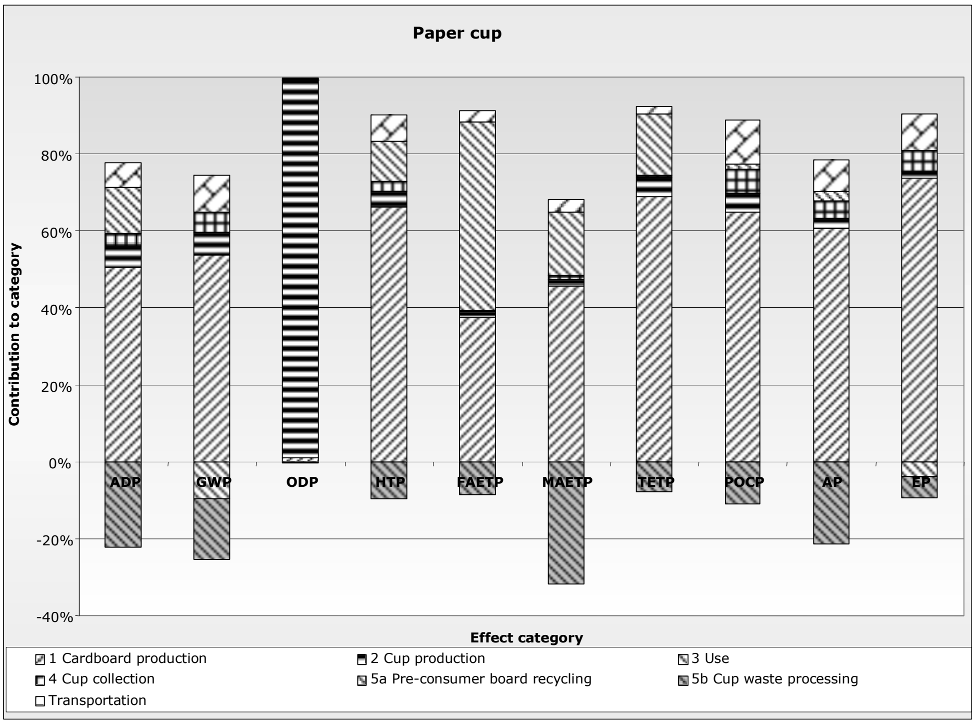

Figure 17 Environmental profile for the disposable paper cup coated with PE.

The disposable paper cup coated with PE clearly shows the advantages of waste processing of used cups in the MSWI in the environmental profile; clearly negative contributions occur especially for ADP, GWP, MAETP and AP (see Figure 17). Energy recovery in the MSWI, for example, produces an advantage for ADP through the fossil fuels saved that are otherwise used for conventional power generation.

Table 19 Environmental profile of the disposable paper cup.

Category	Unit	Total
ADP	kg Sb eq.	4.10E-02
GWP	kg CO_2 eq.	3.81E+00
ODP	kg CFC-11 eq.	3.77E-05
HTP	kg 1.4-DB eq.	3.01E+00
FAETP	kg 1.4-DB eq.	9.22E-01
MAETP	kg 1.4-DB eq.	1.37E+03
TETP	kg 1.4-DB eq.	4.33E-02
POCP	kg C_2H_2	2.20E-03
AP	kg SO_2 eq.	2.92E-02
EP	kg PO_4^{3-} eq.	7.03E-03

The most important contributions/emissions for the very to most important life stages appear in Table 20.

Table 20 Most important contributions/emissions of the very to most important life stages of the disposable paper cup to the effect categories.

Category	1[1] Paper production	2[1] Cup production	5b[1] Paper waste processing
ADP	Extracting coal, gas and oil		Fossil fuels avoided in electricity generation
GWP	CO_2 emission		
ODP		Halon-1301 mineral oil extraction	
HTP	Dioxines emission		
FAETP	Ni and Zn emissions		
MAETP	HF emission		HF emission avoided (electricity generation)
TETP	V and Hg emissions		
POCP	SO_2 and CO emissions		
AP	SO_2 and NO_x emissions		SO_2 and NO_x emissions (electricity generation)
EP	NO_x and COD emissions		

1 The digits refer to the life stages (see Figure 2).

Emissions and avoided emissions of heavy metals play an important role in the values of the effect categories HTP, FAETP and TETP. The most important reason is the combustion of fuels for generating energy. On eutrophication the chemical oxygen demand (COD) in the cardboard factory's waste water also has a bearing.

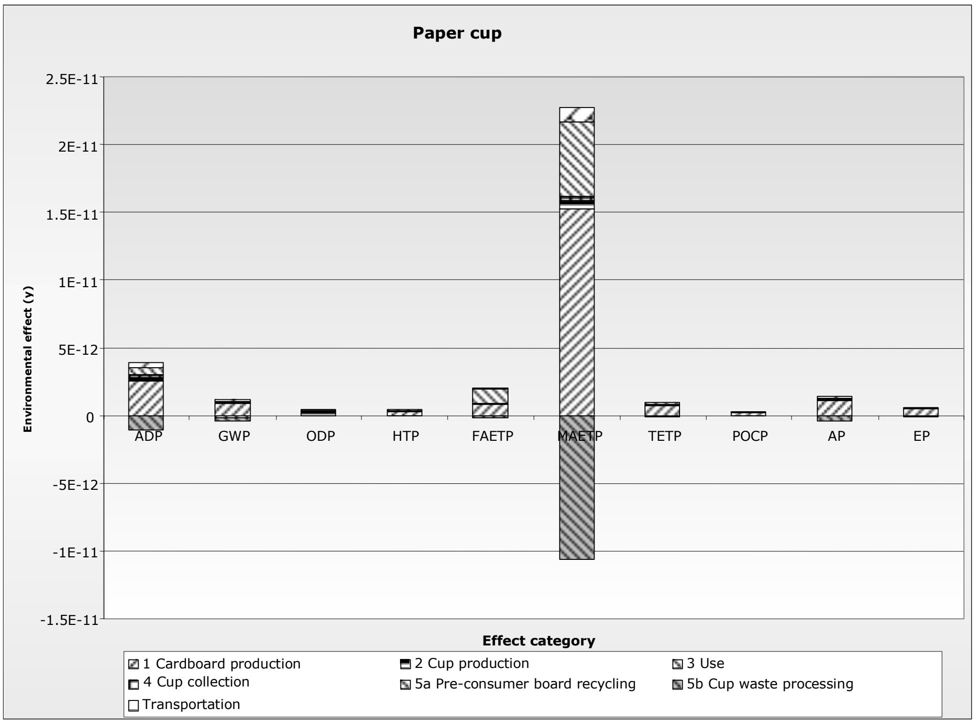

Figure 18 Normalised environmental profile of the disposable paper cup.

The negative contribution under MAETP stands out in the normalised environmental profile (Figure 18). After MAETP, ADP is the effect category with the highest score.

4.7 Comparison of drinking systems

When comparing the various systems, differences less than 20% will be regarded as insignificant.

ISO 14040 permits only the comparison of alternatives by individual effect category. Reference may be made to Figure 19 for this comparison. The scores represented in Figure 19 show that the reusable earthenware mug is the most environmentally polluting system for seven of the ten categories (ADP, GWP, HTP, MAETP, TETP, POCP and AP).

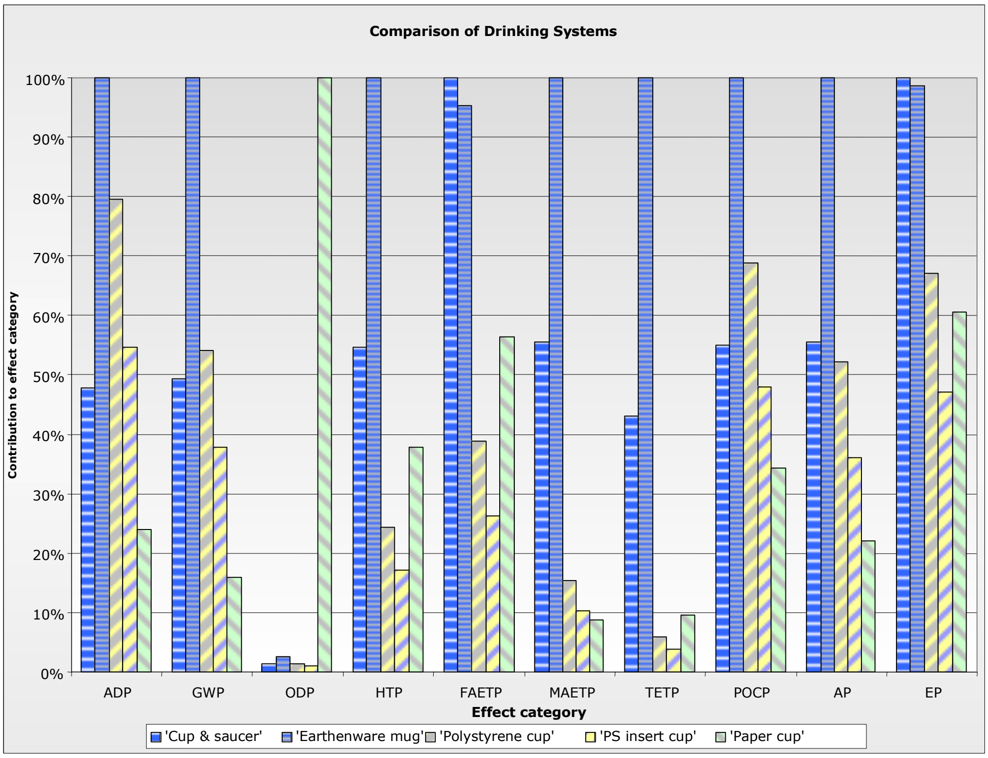

Figure 19 Comparison of the five drinking systems investigated.

The disposable paper cup is the least environmentally polluting system for five of the ten categories (ADP, GWP, MAETP, POCP and AP). For the other five categories, the disposable PS insert cup is the least environmentally polluting system. For ODP, the disposable paper cup scores highest of all. The reusable porcelain cup and saucer scores the highest for two categories (FAETP and EP) and the reusable earthenware mug scores highest for the other 7 categories (ADF, GWP, HTP, MAETP, TETP, POCP and AP). The disposable polystyrene cup does not score highest nor lowest when examining the scores of the 10 categories.

However, when comparing the various drinking systems, account must be taken of the major uncertainties and variation in the values of the main parameters such as life time of the porcelain cup and saucer and of the earthenware mug, the method (frequency and consumption of energy and detergent) of washing up under reusable systems, waste processing of disposable cups, etc. Consequently, conclusions cannot as yet be drawn from this comparison. The results of the sensitivity analyses made in the following chapter are therefore of essence when drawing more final conclusions.

5. Sensitivity analyses

5.1 Introduction

A sensitivity analysis is a systematic procedure for determining to what degree calculation methods and assumptions chosen for the values of the main parameters in the inventory phase determine the outcome of the LCIA [27], [29]. The method of allocation, as used for recycling for example, may also be subject of a sensitivity analysis [27].

The results of this study have shown that the following subjects are eligible for a sensitivity analysis:
1. The raw materials and production of the cup itself are of importance for single use systems. The variability of cup weight therefore plays a role.
2. Cleaning the cups for reusable systems. How often the cup is cleaned and the water and energy consumption per cleaning, in particular, have a bearing.
3. The life time of cups for reusable systems. For the purposes of this study, 3,000 times was chosen for their life time. This assumption, also made by Tauw [1], [2], is fraught with uncertainty. Under the assumed life time the porcelain cup and saucer and earthenware mug themselves have negligible to slight influence on the total environmental burden of the system as a whole. The position may be different on appreciably shorter life times.
4. Using disposable cups more often. It was assumed for the initial situation that the user uses the cup only once. A cup may sometimes also be used several times. This affects the total quantity of cups used and consequently the environmental burden of the system as a whole.
5. Recycling PS disposable cups as scenario after use. Important processes in this case are organising transportation and the bonus offered for recycling (see also [4]). It was assumed for the initial situation that the value of the recycled PS material is 50% of that of the primary GPPS. This value at present seems to exceed 60%.
6. Incineration of disposable cups as a scenario after use. Instead of recycling disposable cups, they can also be processed together with office waste. They are then predominantly incinerated in an MSWI. For energy-containing materials such as plastics, incineration in the MSWI is a fairly environmentally friendly solution since energy is recovered. Another possibility is to use the cup waste for producing so-called sub-coal which saves on the use of pulverised coal in power plants.

The aspects selected for sensitivity analysis appear in Table 21.

Table 21 Aspects for sensitivity analysis.

Subject	Basic scenario	Sensitivity aspects
Reusable systems utilisation stage; number of times used	– Porcelain cup and saucer have a 3000 uses life cycle [1]	– Life cycle of 1500, 1000 and 500 times used
Reusable systems utilisation stage; cleaning frequency	– Cup and saucer: cleaning whenever used – Mug: cleaning whenever used	– Porcelain cup and saucer: cleaning after 2 or 4.5 times used – Earthenware mug: cleaning after 2 or 4.5 times used
Reusable systems utilisation stage; water and energy consumption for dishwasher	– Dishwasher: 0.0184 kWh, 0.126 l water and 0.4 gr detergent per cup cleaned – Manual: 0.4 l hot water, 0.109 kWh per wash	– TAUW dishwasher, 70% and 130% energy consumption – Manual; cold water use instead of hot water; 0.2 and 0.6 l hot water per wash
Disposable systems production stage; cup weight variation	– PS insert cup: 2.7 grams – PS vending cup: 4.0 grams – Paper cup: 5.0 grams	– Minus and plus 20%.
Disposable systems utilisation stage; number of times used	– Use once only	– 2 and 4.5 times cup use.
Recycling disposable PS cups/insert cups	– Plastics recycling; allocation based on economic value (50%)	– Allocation based on 65% and 90% of primary raw material value
Recycling/incinerating disposable PS (insert) cups and paper cups	– Recycling PS (insert) cups; paper cups 100% MSWI	– 100% MSWI; 100% sub-coal

5.2 Number of times a reusable porcelain cup and saucer are used

The life cycle of the porcelain cup and saucer determines what proportion of the mass of the porcelain cup and saucer is assigned to the thousand uses that comprise the functional unit. For the basic scenario, one third of the weight is assigned. This is because the life cycle is 3,000 times used [1]. Although other public sources do not indicate the life time of a cup and saucer, we know that the life time of porcelain cups and saucers in industrial use is shorter. A life time of 1000 times used is therefore regarded as realistic. A look was therefore taken at the effect of shorter life times of 1500, 1000 and 500 times used. In the latter case, this means that a thousand uses requires two porcelain cups and saucers.

Table 22 Sensitivity of the values of the effect categories to a change in the life time of the porcelain cup and saucer. The basic scenario has been set at 100% for this purpose.

Category	Cup & saucer (3000 times used)	Cup & saucer (1500 times used)	Cup & saucer (1000 times used)	Cup & saucer (500 times used)
ADP	100%	104%	108%	119%
GWP	100%	103%	107%	117%
ODP	100%	108%	115%	139%
HTP	100%	101%	103%	107%
FAETP	100%	101%	102%	105%
MAETP	100%	101%	101%	104%
TETP	100%	100%	100%	101%
POCP	100%	101%	103%	107%
AP	100%	101%	102%	106%
EP	100%	101%	102%	104%

Even a six times shorter life time (500 times used instead of 3,000) results in a greater effect score by not more than 10% for most effect categories (see Table 22). Exceptions are the categories ODP (139%), ADP (119%) and GWP (117%).

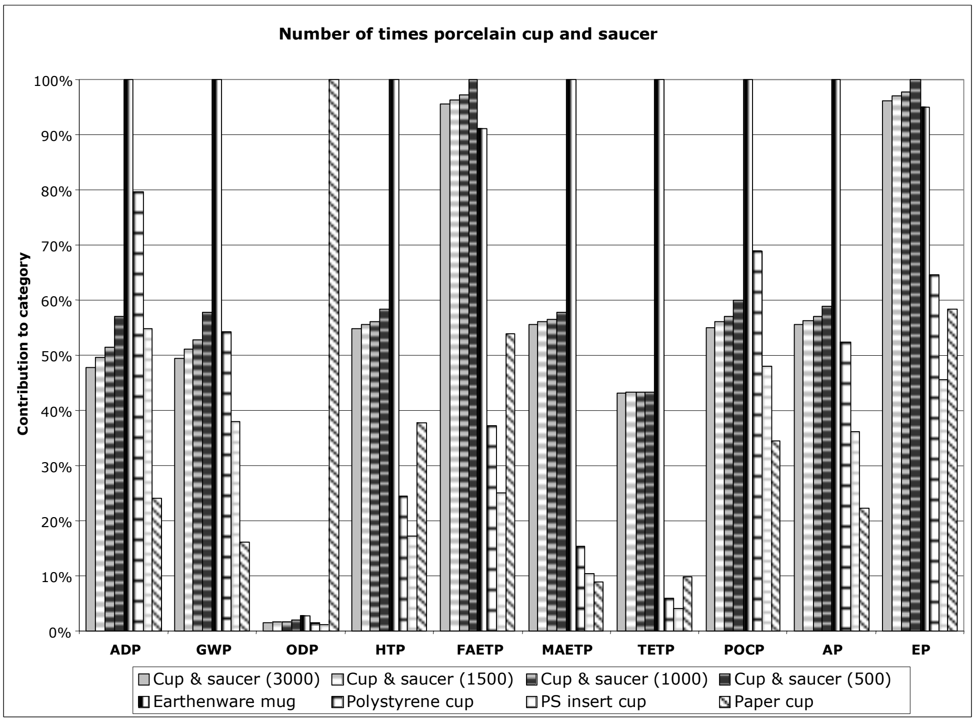

Figure 20 Influence of variation in the lifecycle of the porcelain cup and saucer on the environmental profile. The highest scoring system has been set at 100% per category. The porcelain cup and saucer has a life cycle of 3000 uses in the basic scenario. In the sensitivity analysis, the figure under "cup and saucer (1500)" indicates that the porcelain cup and saucer has a time of 1500 times used.

The porcelain cup and saucer have proved relatively insensitive to changes in life time. A reduction in life time does therefore not result in significant differences in the ranking per effect category for the various systems (see Figure 20).

5.3 Cleaning frequency of reusable systems

The cleaning of reusable systems has a major influence on the values in the effect categories in the environmental profile for the reusable porcelain cup and saucer and reusable earthenware mug (see 4.2 and 4.3). These systems are therefore particularly sensitive to a change in cleaning frequency (see Table 23 and Figure 21). For the reusable porcelain cup and saucer, a reduction in the cleaning frequency from whenever used to after every 2nd use results in a reduction in the environmental burden by approx. 50%. For the reusable earthenware mug, we can also see particular sensitivity to a change in the cleaning frequency (see Table 23).

Table 23 Sensitivity of the values of the effect category for a change In the cleaning frequency of reusable systems. The basic scenario here has been set at 100%.

Category	Porcelain cup & saucer	Porcelain cup & saucer (2) [1]	Porcelain cup & saucer (4.5) [2]	Earthenware mug	Earthenware mug (2)[1]	Earthenware mug (4.5)[2]
ADP	100%	52%	25%	100%	50%	23%
GWP	100%	52%	25%	100%	50%	23%
ODP	100%	54%	28%	100%	51%	24%
HTP	100%	51%	23%	100%	50%	22%
FAETP	100%	50%	23%	100%	50%	23%
MAETP	100%	50%	23%	100%	50%	22%
TETP	100%	50%	22%	100%	50%	22%
POCP	100%	51%	23%	100%	50%	22%
AP	100%	51%	23%	100%	50%	22%
EP	100%	50%	23%	100%	50%	22%

1 cleaning after being used twice.

2 cleaning after being used 4.5 times.

The frequency with which reusable systems are cleaned clearly affects the environmental profile of these systems. This applies especially to the effect categories GWP, HTP, FAETP, MAETP and EP, to which the porcelain cup and saucer contribute most with the high cleaning frequency (after every use) (see Figure 21).

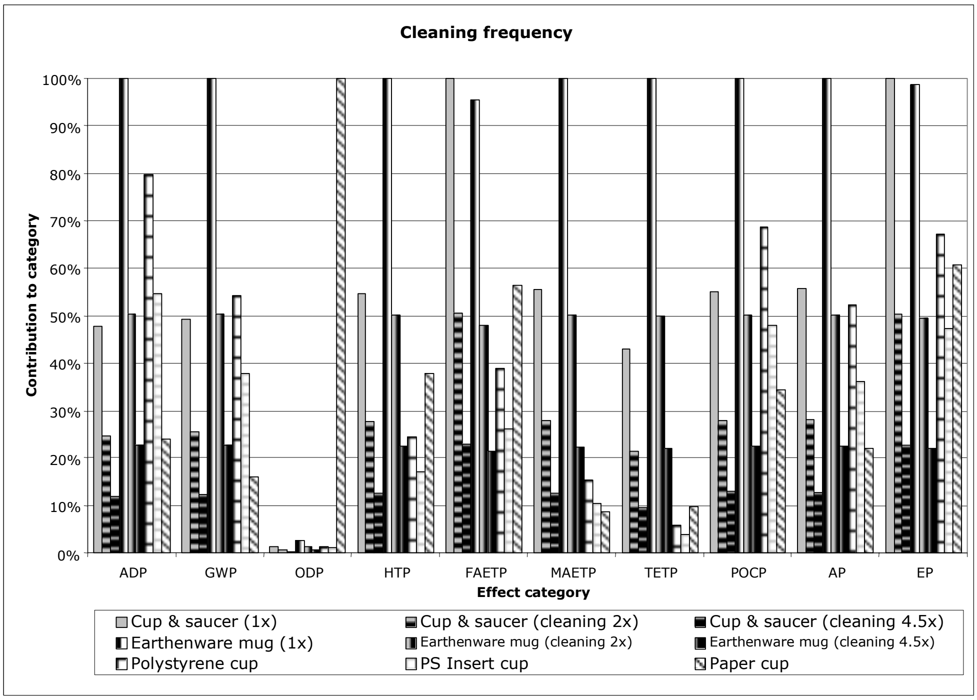

Figure 21 Influence of the change in the frequency of cleaning reusable systems. The highest scoring system has been set at 100% per category (cleaning 2). In the basic scenario, the reusable systems are directly cleaned whenever used. In the sensitivity analysis,(cleaning 2x) means cleaning after 2 uses, (cleaning 4.5x) means cleaning after 4.5 uses.

For the toxicity categories (HTP, FAETP, MAETP, TETP), the reusable porcelain cup and saucer will do better or equally when compared with the disposable polystyrene cup if they are cleaned only after being used 4.5 times. The reusable porcelain cup and saucer is very sensitive to changes in the frequency of cleaning; changes have a virtually proportional effect on the values in the environmental profile (see Figure 21). Because the user in case of reusable systems has a great degree of freedom with regard to cleaning frequency, conclusions can be drawn only on the basis of a specific situation.

5.4 Energy use of dishwasher

One of the major uncertainties with the system of reusable porcelain cups and saucers is the energy used by the dishwasher. This energy consumption has a major influence on the environmental profile of this system. Under the basic scenario, the dishwasher uses 0.0124 kWh per cup and saucer for washing and 0.006 kWh for drying. The values adopted for the sensitivity analysis for these values are 70% and 130%.

Table 24 Sensitivity of the values of the effect categories to a change in energy consumption of the dishwasher when cleaning the porcelain cup and saucer. The basic scenario here has been set at 100%. The scenario "washer 70" relates to the effect of 70% energy consumption of the basic scenario; "washer 130" to 130%.

Category	Cup & saucer	Cup & saucer (washer 70)	Cup & saucer (washer 130)
ADP	100%	74%	126%
GWP	100%	75%	125%
ODP	100%	77%	122%
HTP	100%	77%	123%
FAETP	100%	88%	112%
MAETP	100%	77%	123%
TETP	100%	71%	129%
POCP	100%	78%	122%
AP	100%	78%	122%
EP	100%	93%	107%

For terrestrial ecotoxicity (TETP) the effect of a change in energy consumption by the dishwasher is the strongest; for eutrophication (EP), the effect is the smallest (see Table 24). For the highest energy consumption, reusable porcelain cup and saucer now scores higher for GWP than the disposable polystyrene cup system (see Figure 22).

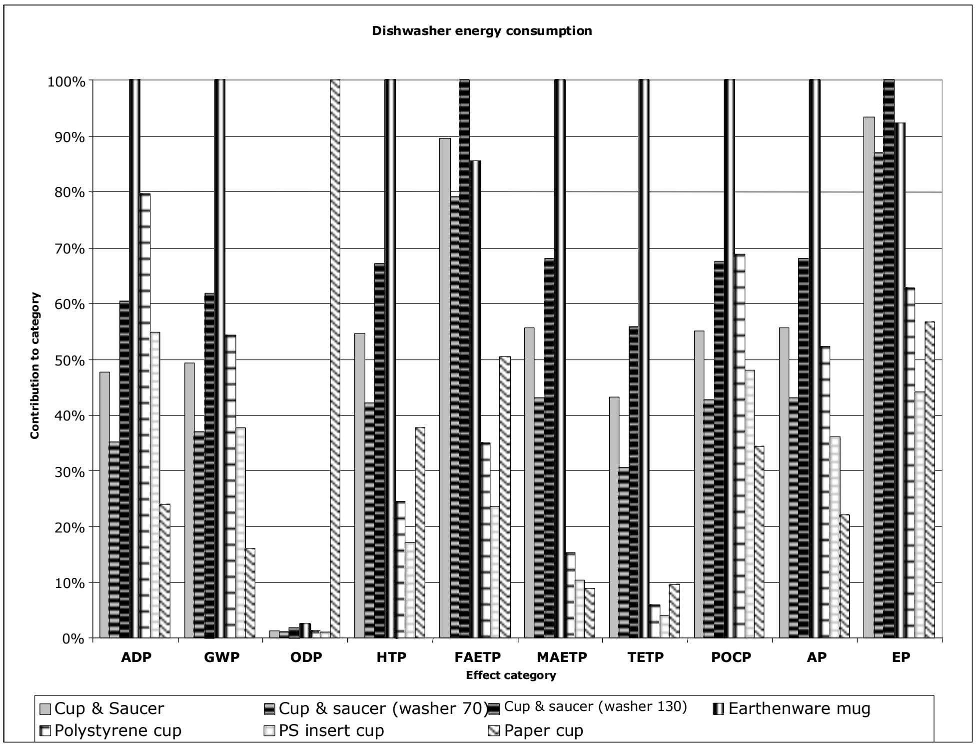

Figure 22 Influence of the change in energy consumption in a dishwasher for cleaning porcelain cup and saucer on the environmental profile. The highest scoring system per category has been fixed at 100%. The addition "washer 70" indicates an energy consumption of 70% of the basic scenario; "washer 130" of 130%.

The energy consumption of dishwashers available on the market place varies tremendously [13]. Because this variation has a strong effect on the environmental profile of the reusable porcelain cup and saucer, this produces relatively great uncertainty in the environmental profile of the reusable porcelain cup and saucer.

5.5 Water and energy consumption

In the basic scenario for this study, the use of water, energy and detergents in a trade dishwasher was based on data mentioned in the study "Reusable versus Disposable" [5]. The TAUW study [1] indicates energy consumption and detergent use for cleaning porcelain. The effect of using these, older data, on the environmental profile of the reusable porcelain cup and saucer is shown below. Because the TAUW report does not indicate water consumption in the dishwasher, it is assumed that this water consumption is equal to the value adopted for the basic scenario in this study.

Applying the dishwasher data in accordance with the TAUW study results in an increase in environmental impact of approx. 25% (see Table 25). The most sensitive category in this case is TETP; the least sensitive is FAETP.

Table 25 Sensitivity of the values for the effect categories on a change in environmental data from the dishwasher for reusable porcelain cups and saucers. The basic scenario has been set at 100% here. "(TAUW)" indicates the scenario of using the dishwasher in accordance with [1].

Category	Cup & Saucer	Cup & Saucer (TAUW)
ADP	100%	126%
GWP	100%	126%
ODP	100%	124%
HTP	100%	124%
FAETP	100%	117%
MAETP	100%	124%
TETP	100%	129%
POCP	100%	124%
AP	100%	124%
EP	100%	133%

For the effect categories HTP, FAETP, POCP, AP and EP, use of the TAUW data produces a change in the system rankings (see Figure 23). As far as the basic scenario is concerned, the reusable porcelain cup and saucer score better than the disposable polystyrene cup under POCP and GWP. On application of TAUW data, both systems score equally or the disposable polystyrene cup even scores better.

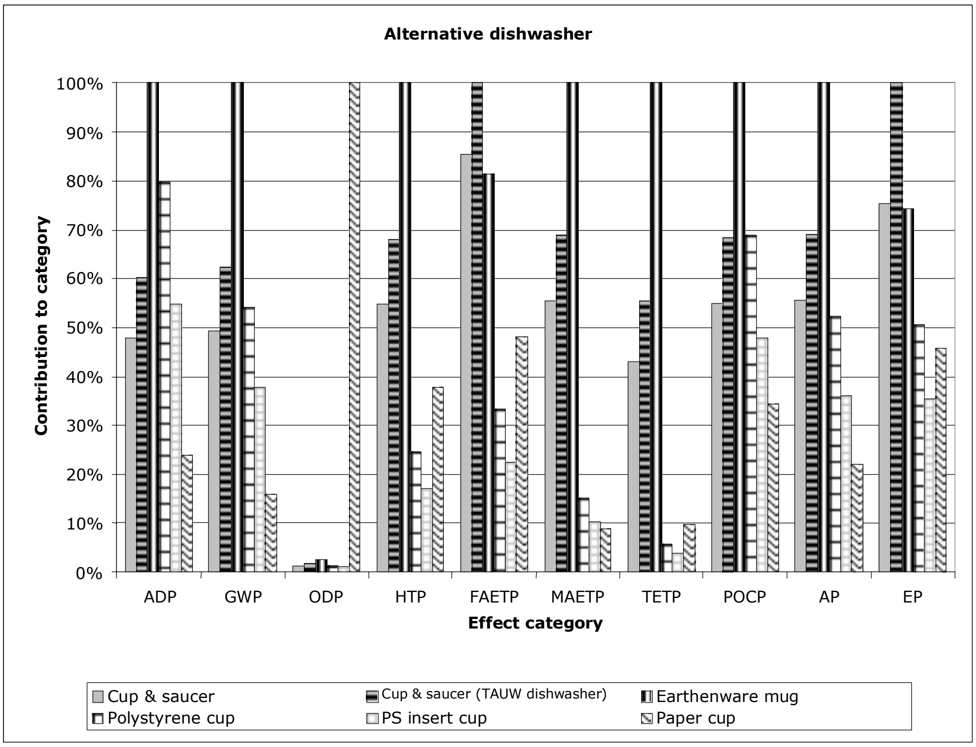

Figure 23 Influence of the change in environmental data for the dishwasher for the porcelain cup and saucer on environmental profile. The system scoring highest per category has been set at 100%. "TAUW dishwasher" indicates the scenario where the data for the dishwasher from [1] have been used.

Comparing the basic scenario in the present study with that using the TAUW data shows that the values for the porcelain cup and saucer for FAETP and EP change from "equivalent" to "poorer" performing.

For the earthenware mug that the user cleans himself, 0.4 l hot water from a kitchen boiler is used for each wash up. It is a fact that some users use cold water[1] in practice for cleaning the mug; they do so despite the fact that this is inadvisable from a hygiene point of view. The effect of this is determined by a sensitivity analysis. In addition, an analysis has been made for the effect of using 0.2 and 0.6 l hot water per mug cleaning.

1 In the light of the Hazard Analysis and Critical Control Points (HACCP) principles question marks can be placed regarding the hygiene of the system when the cleaning aspects are changed [37].

Table 26 Sensitivity of the values of the effect categories for a change in cleaning circumstances for the reusable earthenware mug. The basic scenario is set at 100% in this case.

Category	Earthenware mug (basic scenario)	Earthenware mug (use 0.2 l hot water)	Earthenware mug (use 0.6 l hot water)	Earthenware mug (use cold water)
ADP	100%	50%	150%	1%
GWP	100%	50%	150%	1%
ODP	100%	51%	149%	3%
HTP	100%	50%	150%	1%
FAETP	100%	50%	150%	4%
MAETP	100%	50%	150%	1%
TETP	100%	50%	150%	1%
POCP	100%	50%	150%	2%
AP	100%	50%	150%	1%
EP	100%	50%	150%	45%

Table 26 indicates the effect of changing the quantity of hot water for cleaning the reusable earthenware mug on the values of the effect categories. The effect of using cold instead of hot water results in a very sharp reduction in the effect category values. The categories TETP and MAETP, for example, fall to 1% of the original values. The value for eutrophication is relatively the least sensitive and falls to 45% of the original value.

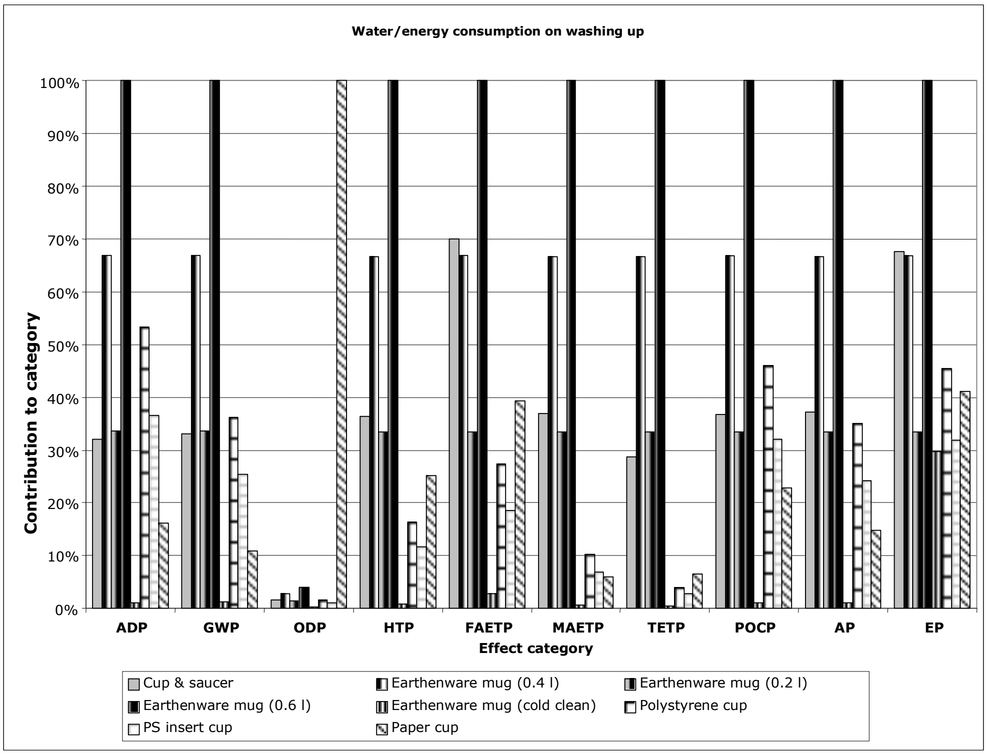

Figure 24 Influence of the change in the quantity of hot water for washing up the earthenware mug. The highest scoring system per category has been set at 100%. In the basic scenario, the earthenware mug is cleaned with 0.4 l hot water. Alternatives are "0.2 l" cleaning with 0.2 l hot water. "0.6 l" cleaning with 0. 6 l hot water and "cold clean" cleaning with cold water.

As the figures in Table 26 show, the use of cold water shows a very sharp reduction in the effect category values. This results in the earthenware mug proving the best scoring system, although hygienically questionable, for all categories under these circumstances (see Figure 24). The use of the quantity of hot water also affects the ranking of the systems considered.

The large number of possibilities that the user has for cleaning the earthenware mug and the consequent particular sensitivity of the environmental profile of this system means that no statement can be made in advance as to its environmental performance.

5.6 Variation in cup weights for disposable systems

In the disposable systems, the weight of the cup plays an important role because the production of the raw material and that of the cup itself contributes significantly to the environmental profile. Consideration has been given for these systems to the effects of a variation in weight by 20% either way. It is assumed here that the effects of collecting the used cups on the effect category values are directly proportional to the weight of the disposable cups.

Table 27 Variation in weight of disposable cups for the sensitivity analysis.

Cup type	Basic weight (g)	Basic -20% (g)	Basic +20% (g)
Polystyrene	4.0	3.2	4.8
PS insert cup	2.66	2.13	3.20
Paper cup	5.0	4.0	6.0

The results stated in Table 28 show that the change in weight has a proportional onward effect on the values of the effect categories. This is due to the environmental effects being fully linked to the weight of the cups during all life stages of the polystyrene and paper cup. For the PS insert cup, this linkage is nearly 100% because the cup holder, the weight of which is unvaried, makes a negligible contribution.

Table 28 Sensitivity of the values of the effect categories to a change in the weight of disposable cups. The basic scenario has been set at 100% in this case.

Category	Polystyrene cup (4.0 grams)	Polystyrene cup (3.2 grams)	Polystyrene cup (4.8 grams)	PS insert cup (2.66 grams)	PS insert cup (2.13 grams)	PS insert cup (3.20 grams)	Paper cup (5.0 grams)	Paper cup (4.0 grams)	Paper cup (6.0 grams)
ADP	100%	80%	120%	100%	80%	120%	100%	80%	120%
GWP	100%	80%	120%	100%	80%	120%	100%	80%	120%
ODP	100%	80%	120%	100%	80%	120%	100%	80%	120%
HTP	100%	80%	120%	100%	80%	120%	100%	80%	120%
FAETP	100%	80%	120%	100%	80%	120%	100%	80%	120%
MAETP	100%	80%	120%	100%	80%	120%	100%	80%	120%
TETP	100%	80%	120%	100%	80%	120%	100%	80%	120%
POCP	100%	80%	120%	100%	80%	120%	100%	80%	120%
AP	100%	80%	120%	100%	80%	120%	100%	80%	120%
EP	100%	80%	121%	100%	80%	120%	100%	80%	120%

The change in cup weight in disposable systems does not always result in changes in the ranking when comparing with reusable systems. An exception, for example, is the ADP value of the disposable PS insert cup with the lowest weight, which is now equal to that of the porcelain cup and saucer.

Another example is the disposable paper cup, which at the lowest weight, scores better than the cup and saucer for HTP and EP. Ranking differences occur especially between disposable cups mutually, if the cup with the lowest weight is compared with another disposable cup with the highest weight. For GWP, for example, it is clear that the disposable polystyrene insert cup with the highest weight scores poorer than the disposable polystyrene cup with the lowest weight (Figure 25).

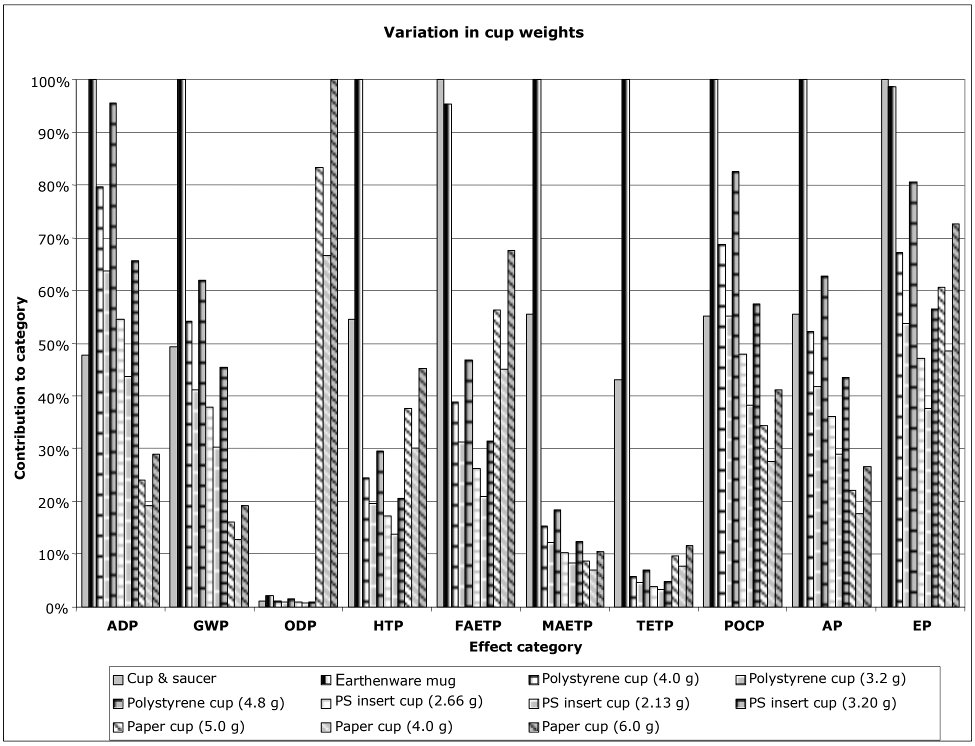

Figure 25 *Influence of a change in the weight of the disposable cup. The highest scoring system per category has been set at 100%. In the basic scenario, the polystyrene cup weighs 4.0 grams, the PS insert cup 2.66 grams and the paper cup 5.0 grams. Alternatives are 80% of the basic scenario and 120% of the basic scenario. The adjusted weights are shown between brackets.*

In practice, there is a spread in the weights of the disposable cups which is reflected one to one in the environmental profile of these cups.

5.7 Number of times disposable systems are used

Multiple use of disposable cups occurs in practice; the same cup is commonly used more than once for coffee or tea. Using twice and using 4.5 times have been investigated as variants in the sensitivity analysis. This more frequent use is translated into lower cup consumption per 1,000 times used of 50% and 22.2% respectively. In view of the results under 5.6, the values of the effect categories will therefore reduce by the same percentages. This is in fact the case for the disposable polystyrene and disposable paper cup; there is a negligible divergence for the disposable PS insert cup (see Table 29) since the cup holder determines a negligible to hardly important part of the environmental profile.

Table 29 Sensitivity of the values of the effect categories to repeated use of the disposable cup. In this case the basic scenario has been set at 100%. Divergences may occur through rounding off.

Category	Polystyrene cup	Polystyrene (using twice)	Polystyrene (using 4.5 times)	PS insert cup	PS insert cup (using twice)	PS insert cup (using 4.5 times)	Paper cup	Paper cup (using twice)	Paper cup (using 4.5 times)
ADP	100%	50%	22%	100%	51%	23%	100%	50%	22%
GWP	100%	50%	22%	100%	49%	23%	100%	50%	22%
ODP	100%	50%	22%	100%	52%	26%	100%	50%	22%
HTP	100%	50%	22%	100%	50%	23%	100%	50%	22%
FAETP	100%	50%	22%	100%	50%	22%	100%	50%	22%
MAETP	100%	50%	22%	100%	50%	22%	100%	50%	22%
TETP	100%	50%	22%	100%	50%	23%	100%	50%	22%
POCP	100%	50%	22%	100%	50%	23%	100%	50%	22%
AP	100%	50%	22%	100%	50%	23%	100%	50%	22%
EP	100%	50%	22%	100%	50%	23%	100%	50%	22%

On being used twice, differences already occur in the ranking. We see for GWP (Figure 26) that the disposable polystyrene cup now scores better than the reusable porcelain cup and saucer. This is also evident for ADP. On using 4.5 times, sharp differences arise in ranking. The environmental profile of the disposable polystyrene cup is therefore now more favourable than that of the reusable porcelain cup and saucer. Repeated use of disposable cups affects the comparison of scores with those of all other systems.

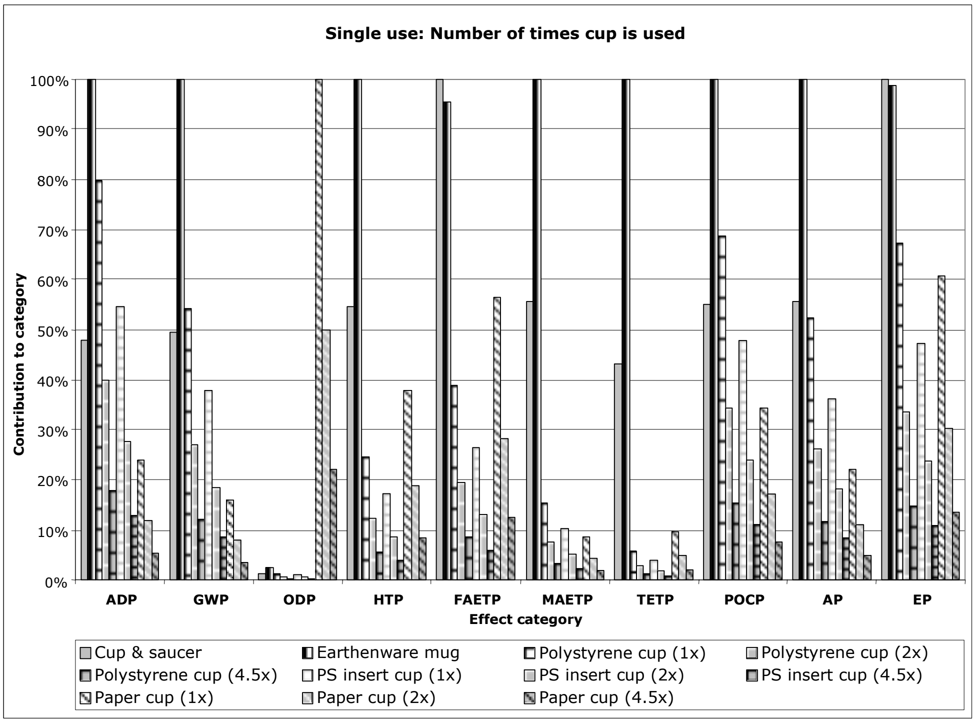

Figure 26 *Influence of repeated use of disposable cups on the environmental profile. The highest scoring system per category has been set at 100%. In the basic scenario, disposable cups are used only once. Alternatives are: "2x" using twice; "4.5x" using 4.5 times.*

Disposable cups are very sensitive to repeated use of the cup, whereupon the environmental burden reduces sharply. Because the user decides how often he uses the cup (disposable), general statements about the environmental impact of disposable systems compared with that of reusable systems cannot easily be made.

5.8 Allocation based on the economic value of recycled plastics

In the basic scenario, the recycling of plastics is allocated on the basis of an economic value of 50%[1]. An allocation based on 65% and 90% of the economic value has been made as sensitivity analysis. This enhances the bonus from avoided production of primary raw material.

The change in the allocation from 50% avoided production to 65% avoided production produces no differences in excess of 20%. (See Table 30). On the other hand, the scenario based on an allocation of 90% avoided production indicates

[1] 50% allocation means that an economic value is attached to the recyclate of 50% of that allocated to the virgin PS granulate. 1 kg of recyclate therefore prevents environmental impact by 0.5 kg of virgin PS granulate.

differences under five categories (ADP, GWP, AP and EP) in excess of 20%. With ADP in particular, the systems are sensitive to a change in allocation of avoided production through recycling.

Table 30 Sensitivity of the values of the effect categories to allocation based on the economic value of the primary production avoided through recycling the disposable PS cups. The basic scenario in this case is set at 100%.

Category	Polystyrene cup (50% allocation)	Polystyrene cup (65% allocation)	Polystyrene cup (90% allocation)	PS insert cup (50% allocation)	PS insert cup (65% allocation)	PS insert cup (90% allocation)
ADP	100%	84%	55%	100%	84%	56%
GWP	100%	84%	63%	100%	84%	64%
ODP	100%	100%	100%	100%	100%	100%
HTP	100%	99%	95%	100%	99%	96%
FAETP	100%	98%	95%	100%	98%	95%
MAETP	100%	99%	96%	100%	99%	96%
TETP	100%	97%	88%	100%	97%	88%
POCP	100%	89%	70%	100%	90%	71%
AP	100%	87%	63%	100%	87%	64%
EP	100%	89%	70%	100%	90%	72%

With regard to ranking, some differences occur under the scenarios with the higher allocation percentages, compared with the environmental profiles for the reusable porcelain cup and saucer (see Figure 27). For the basic scenario, the disposable polystyrene cup scored higher under GWP than the reusable porcelain cup and saucer. In the event of 65% allocation, both systems score equally and in that of 90% allocation, the disposable polystyrene cup scores better. A comparable situation arises for POCP and AP. For ADP, the disposable polystyrene cup approximates the value of the reusable porcelain cup and saucer on increasing allocation; the position of the disposable PS insert cup even becomes better than that of the reusable porcelain cup and saucer on increasing allocation.

The disposable polystyrene cup and disposable PS insert cup are relatively sensitive to the specific allocation based on the economic value of the environmental advantage of material recycling.

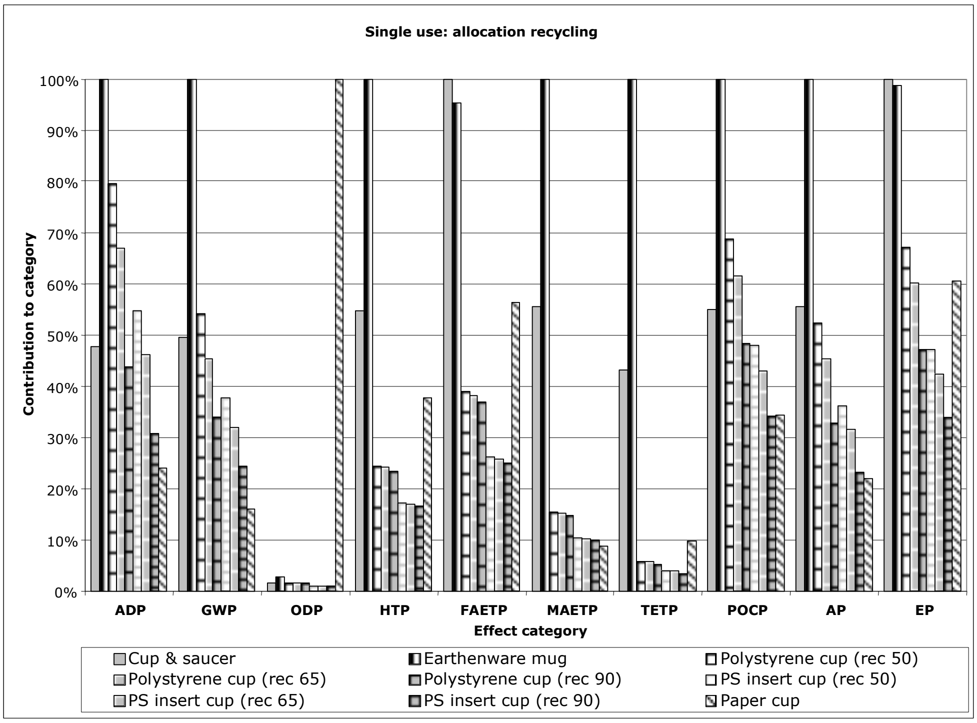

Figure 27 Influence of allocation of plastic production avoided through recycling of single use PS cups on the environmental profile. The highest scoring system per category has been set at 100%. In the basic scenario, 50% of avoided production is allocated to recycling. Alternatives are: "rec 65", 65% allocation and "rec 90", 90% allocation.

5.9 European post consumer waste scenario

Cup recycling systems other then the Dutch system for post consumer polystyrene cup waste from sources such as commerce, offices and public institutions do exist in Western Europe (e.g. UK and Switzerland) but most of this waste will go to waste treatments like landfill and incineration.

Based on the most recent figures (2004, 2005) on municipal solid waste treatment in the EU15 a waste scenario for polystyrene (insert) cups and paper cups has been defined:

- Landfill 78.0%
- Incineration 22.0%
  - with energy recovery 14.9%
  - no energy recovery 7.1%

Table 31 Sensitivity of the values of the effect categories to changing the waste scenario to the EU-15 landfill-incineration scenario. The basic scenario in this case is set at 100%.

Category	Polystyrene cup	Polystyrene cup (waste EU-15)	PS insert cup	PS insert cup (waste EU-15)	Paper cup	Paper cup (waste EU-15)
ADP	100%	136%	100%	133%	100%	134%
GWP	100%	137%	100%	130%	100%	145%
ODP	100%	49%	100%	42%	100%	100%
HTP	100%	45%	100%	41%	100%	111%
FAETP	100%	54%	100%	54%	100%	109%
MAETP	100%	62%	100%	61%	100%	175%
TETP	100%	53%	100%	52%	100%	108%
POCP	100%	110%	100%	103%	100%	118%
AP	100%	127%	100%	121%	100%	132%
EP	100%	108%	100%	99%	100%	107%

The change of the base case waste scenario where the polystyrene cups are collected for recycling and the paper cups are incinerated with energy recovery to the EU-15 waste scenario leads to changes in the environmental profile (see Table 31 and Figure 28) and to some changes in ranking of the systems. The latter occurs for ADP and AP where the polystyrene cup now has an impact higher than that of the cup and saucer. For GWP the polystyrene insert cup gets now a comparable performance.

For a number of impact categories the performance of the polystyrene (insert) cup becomes better for the EU-15 waste scenario. This is especially so for the toxicity related categories (HTP, FAETP, MAETP and TETP) and ODP. Regarding the EU-15 scenario no cardboard boxes are used for the waste collection, no separate vans do collect the waste and less electricity is used.

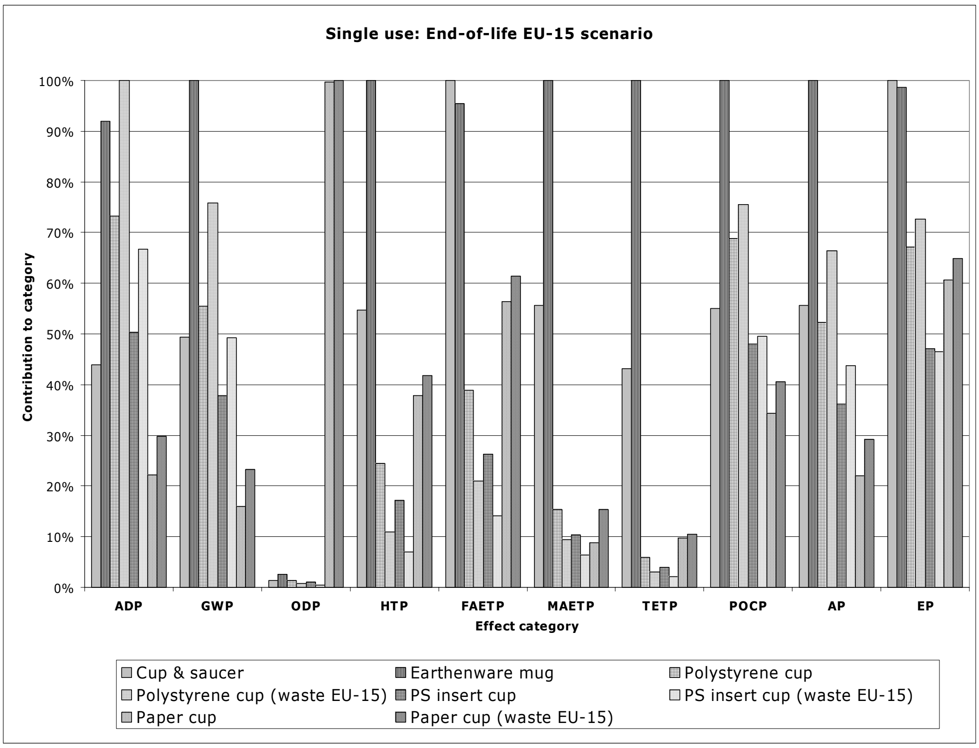

Figure 28 Influence of the EU-15 waste scenario for the single use systems on the environmental profile. The highest scoring system per category has been set at 100%.

5.10 Alternative end-of-life routes for disposable cups

In accordance with the basic scenario, used disposable polystyrene cups proceed to a recycling facility under the Stichting Disposables Benelux collection system for processing into secondary PS raw material. Other routes at the end of the life cycle are of course possible. Disposable polystyrene cups consequently also proceed to the MSWI with the rest of the office waste. As an alternative, so-called sub-coal is made from this waste fraction to replace pulverised coal in a power plant.
For the paper cup made out of PE-coated board the sub-coal energy recovery is also an option and is as such included in this sensitivity analysis.

Before the various scenarios are compared, the influence of each end-of-life cycle alternative (MSWI, or sub-coal) on the environmental profile of the disposable polystyrene cup will be discussed. It is clear that incineration in the MSWI reduces environmental burden by the disposable polystyrene cup (see Table 32 and Figure 28). In the MSWI, power is in fact generated from the combustion heat, which need not then be generated in the conventional manner.[1] Part of the heat released is also usefully applied. This heat therefore needs not be generated in the conventional way[2]. Under ODP and MAETP, the application of the MSWI as waste processing results in an environmental gain for this stage of the life cycle. This is so because more environmental impact is saved by generating energy in the MSWI than that which occurs by way of environmental impact on incineration in the MSWI itself. Under ODP, this is due to avoiding emissions of halons released when generating conventional electricity. Under MAETP, this is the HF emission avoided (combustion of fossil fuel mix).

Table 32 Environmental profile of the disposable polystyrene cup with 100% MSWI as end-of-life scenario.

Category	Unit	Total
ADP	kg Sb eq.	1.55E-01
GWP	kg CO_2 eq.	2.21E+01
ODP	kg CFC-11 eq.	-1.86E-08
HTP	kg 1.4-DB eq.	9.02E-02
FAETP	kg 1.4-DB eq.	1.70E-01
MAETP	kg 1.4-DB eq.	-5.16E+02
TETP	kg 1.4-DB eq.	7.10E-03
POCP	kg C_2H_2	3.99E-03
AP	kg SO_2 eq.	6.92E-02
EP	kg PO_4^{3-} eq.	7.12E-03

1 The avoided production concerns that of the UCTE power production mix (15).

2 The avoided heat production concerns “heat, natural gas, at industrial furnace >100kW/RER” [15]

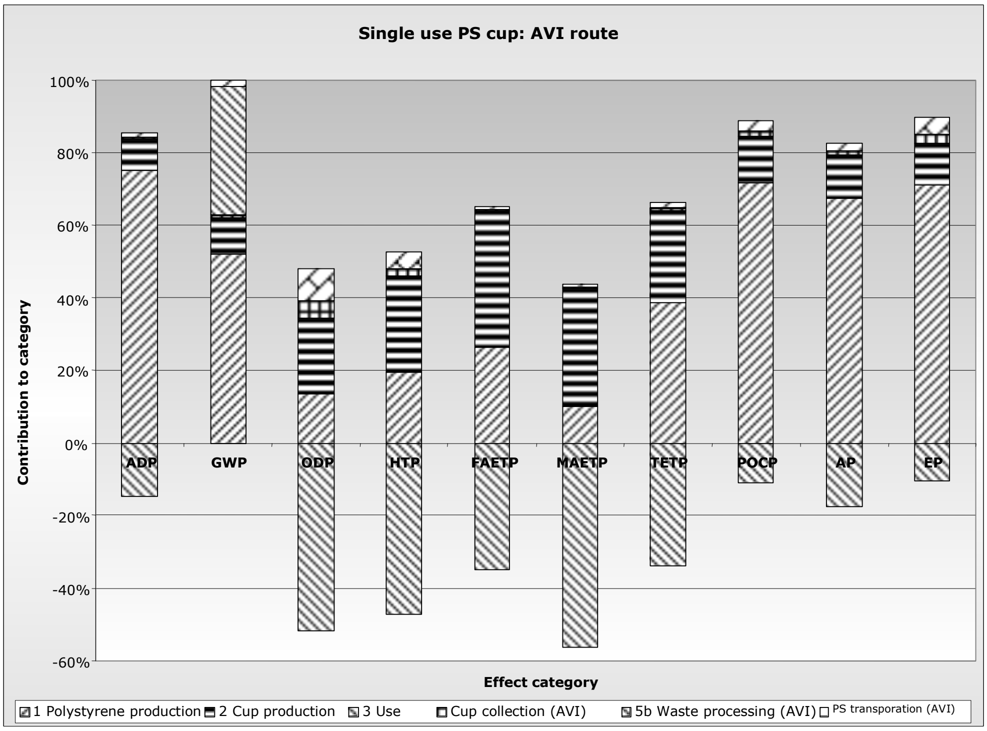

Figure 29 Environmental profile of the single use polystyrene cup with 100% MSWI as end-of-life scenario.

In the case of the sub-coal waste scenario, the cups are collected together with dry office waste (see also [4]). Together with paper waste, polystyrene waste is converted into a fuel for a pulverised coal power plant. Here, the fuel is converted into electricity. A plastic paper fraction (PPF) is separated from the dry office waste in a waste processing plant. Part of the humidity/contamination from the cups (14.6%) is separated and burned in an MSWI. After being pelletised, the PPF can serve as the fuel for, amongst others similar application, the EZH coal fired power plant at Maasvlakte [29]. Before they are burned, the pellets are fine grinded for injecting into the combustion chamber together with the pulverised coal. Sub-coal from disposable PS cups have a relatively high energy content; in this LCA, an LHV is assumed of 34.6 MJ/kg for contaminated polystyrene coffee cups [30]. The coal fired power plant has an energy yield of 40%, which is higher than the 20% energy yield achieved in an MSWI [29]. Generating electricity from sub-coal avoids electricity production from pulverised coal[1].
For the paper cup a LHV of the subcoal has been based on the remaining contamination and the PE:board ratio. The estimated LHV is 16.2 MJ/kg.

1 The production avoided is that of ‘electricity, hard coal at UCTE power plant’ [15].

Table 33 Environmental profile of the disposable polystyrene cup and paper cup on sub-coal processing as end-of-life scenario.

Category	Unit	PS cup	Paper cup
ADP	kg Sb eq.	5.16E-02	-2.84E-02
GWP	kg CO_2 eq.	9.44E+00	-4.37E+00
ODP	kg CFC-11 eq.	2.98E-07	3.79E-05
HTP	kg 1.4-DB eq.	3.94E-02	2.88E+00
FAETP	kg 1.4-DB eq.	3.83E-01	1.04E+00
MAETP	kg 1.4-DB eq.	2.02E+03	2.91E+03
TETP	kg 1.4-DB eq.	-6.04E-03	3.59E-02
POCP	kg C_2H_2	1.27E-03	6.77E-04
AP	kg SO_2 eq.	1.20E-02	-3.00E-03
EP	kg PO_4^{3-} eq.	4.70E-03	6.45E-03

Application of the waste polystyrene cups as sub-coal reduces the environmental burden, whereupon the largest reductions occur for the categories ADP, HTP, TETP, POCP and AP (see Figure 30 and Table 33).

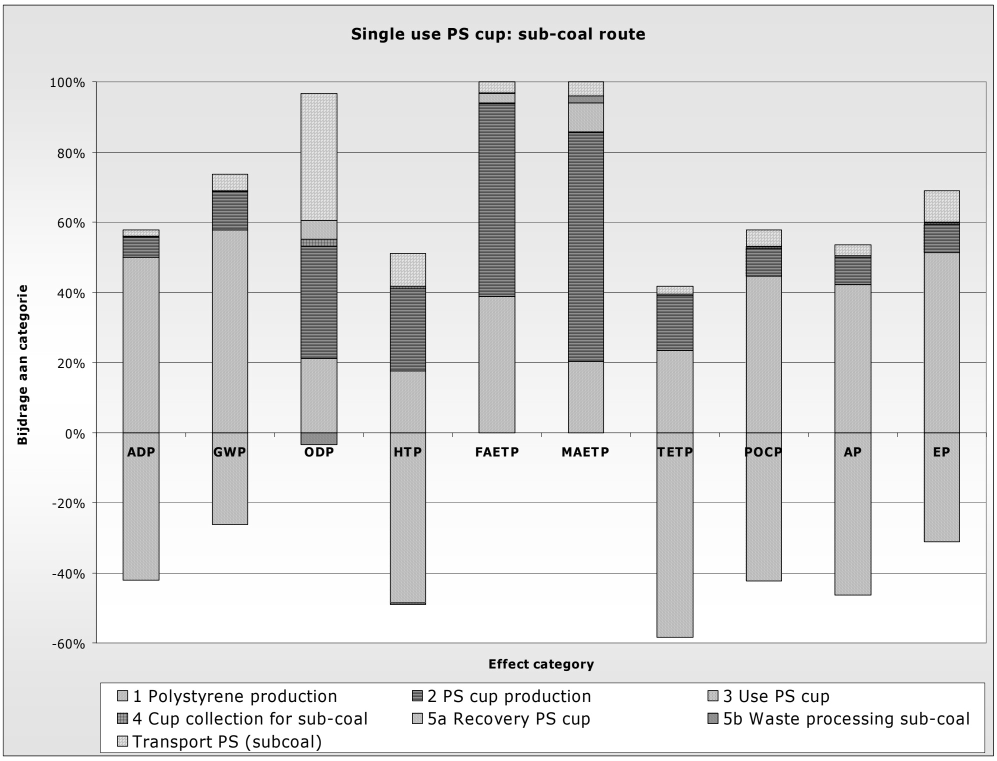

Figure 30 Environmental profile of the disposable polystyrene cup with sub-coal application as end-of-life scenario. The "Recovery PS cup" life cycle includes the production of sub-coal and generation of electricity from sub-coal.

The paper cup also shows the beneficial aspects of the use as sub-coal (see Figure 31). The most marked benefits are for ADP, GWP, POCP and AP. For ADP, GWP and AP the benefits are even larger than the burden of the rest of the system and so a net benefit occurs.

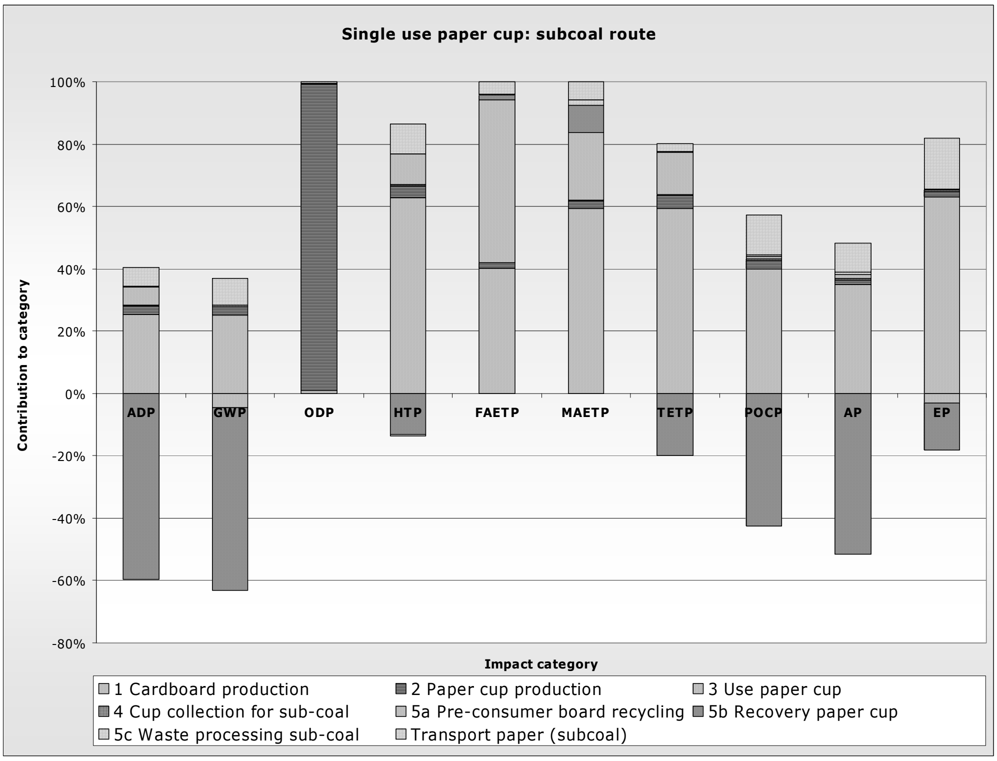

Figure 31 Environmental profile of the disposable paper cup with sub-coal application as end-of-life scenario. The "Recovery paper cup" life cycle includes the production of sub-coal and generation of electricity from sub-coal.

On applying an alternative waste processing scenario, shifts occur in the rankings (see Figure 32). The ranking between the reusable porcelain cup and saucer and the disposable polystyrene cup and disposable PS insert cup, in particular, changes for most effect categories. For ADP, for example, the basic scenario shows a higher score for the disposable polystyrene cup and for the disposable PS insert cup than for the reusable porcelain cup and saucer. On application of the sub-coal route, the disposable polystyrene cup, the disposable PS insert cup and the paper cup perform better than the reusable porcelain cup and saucer. An improvement in the position of the disposable polystyrene cup compared with the reusable porcelain cup and saucer arises under various effect categories, such as e.g. GWP, POCP and AP.

Table 34 Sensitivity of the effect category values to the choice of end-of-life scenario for the disposable PS cup, PS insert cup and paper cup. The basic scenario is in this case set at 100%.

Category	Polystyrene cup (recycling)	Polystyrene cup (MSWI)	Polystyrene cup (sub-coal)	PS insert cup (recycling)	PS insert cup (MSWI)	PS insert cup (sub-coal)	Paper cup (MSWI)	Paper cup (sub-coal)
ADP	100%	114%	38%	100%	112%	35%	100%	-69%
GWP	100%	172%	73%	100%	166%	71%	100%	-115%
ODP	100%	-3%	55%	100%	2%	54%	100%	100%
HTP	100%	5%	2%	100%	5%	1%	100%	96%
FAETP	100%	27%	60%	100%	27%	60%	100%	113%
MAETP	100%	-22%	84%	100%	-21%	83%	100%	212%
TETP	100%	27%	-23%	100%	28%	-25%	100%	83%
POCP	100%	91%	29%	100%	88%	26%	100%	31%
AP	100%	100%	17%	100%	98%	14%	100%	-10%
EP	100%	91%	60%	100%	88%	57%	100%	92%

The choice of the end-of-life route has a clear effect on the environmental profiles of the disposable polystyrene cups and the disposable paper cup. The sub-coal route, in particular, reduces the environmental burden.

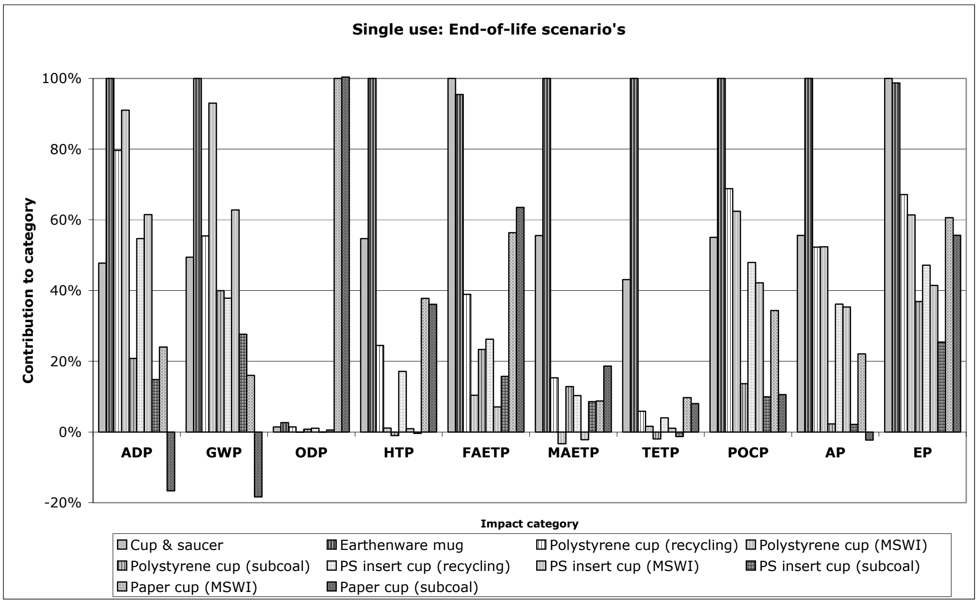

Figure 32 *Influence of the choice of end-of-life scenario for a single use PS cup or insert cup and the paper cup. The highest scoring per category is set at 100%. In the basic scenario the single use polystyrene cups and insert cups are recycled and the paper cup is incinerated in an MSWI.*

5.11 Transition points of the number of times a porcelain cup and saucer are used compared with a disposable polystyrene cup

For a limited number of variables it was investigated when the environmental profile of the disposable polystyrene cup scores better than that of the reusable porcelain cup and saucer. These variables are:

- Life time of cup and saucer (basic scenario; 3000 times used);
- Cleaning frequency of cup and saucer (basic scenario; whenever used);
- Number of times of use of polystyrene cup (basic scenario; used once).

It is clear that if the environmental profile of the disposable polystyrene cup is to be more positive[1] than that of the reusable porcelain cup and saucer, the life time of the latter system must be significantly lower than the 3,000 times used, as assumed for the basic scenario under this study (see Table 35). To have the disposable polystyrene cup score comparably with or better than the reusable porcelain cup and saucer, a life time of 781 times used or less is required for the greenhouse effect (GWP).

Table 35 *Transition points[1] for the life time, cleaning frequency of reusable porcelain cup and saucer and number of uses of disposable polystyrene cups, where the*

[1] The environmental profile is more positive when the values of all effect categories for a system are lower than those for the other system.

scores for the environmental profile of the disposable polystyrene cup and the reusable porcelain cup and saucer are equivalent.

Category	Transition point		
	No. of times used cup and saucer[1]	Cleaning frequency cup and saucer[1]	No. of times used PS cup[1]
ADP	164	< 1	1.7
GWP	781	< 1	1.1
ODP	3043	1.0	-[2]
HTP	-[2]	2.3	-[2]
FAETP	-[2]	2.6	-[2]
MAETP	-[2]	3.7	-[2]
TETP	-[2]	7.4	-[2]
POCP	196	< 1	1.3
AP	-[2]	1.1	-[2]
EP	-[2]	1.5	-[2]

1 A transition point is a point where a system starts to perform better than the system with which it is being compared. A single variable, e.g. the number of uses after which the porcelain cup and saucer are cleaned, is then changed. The comparison is made per environmental effect category (e.g. greenhouse effect or human toxicity). No transition point may possibly exist between two systems for a particular comparison, because the one system always performs better than the other.

2 The polystyrene cup always performs better here than the porcelain cup and saucer.

Another important parameter when comparing the disposable polystyrene cup with the reusable porcelain cup and saucer is the cleaning frequency for the latter. Under the basic scenario, the porcelain cup and saucer are cleaned after each utilisation. For a number of categories, the cleaning frequency (expressed as the number of times used before each cleaning) should in theory be less than 1, if the disposable polystyrene cup is to score better. However, this is not possible in practical terms.

Figure 33 provides clarification for the transition points as to number of times the porcelain cup and saucer are used. For GWP, the reusable porcelain cup and saucer can have a maximum life time of 781 times used (see Table 30). In Figure 33, the disposable polystyrene cup appears on the y-axis (x = 0). If we proceed to the right from this point until we intersect the line for the porcelain cup and saucer, we then see that this arrives at 781 times used on the x-axis. For HTP we see that the disposable polystyrene cup already lies below the line for the reusable porcelain cup and saucer.

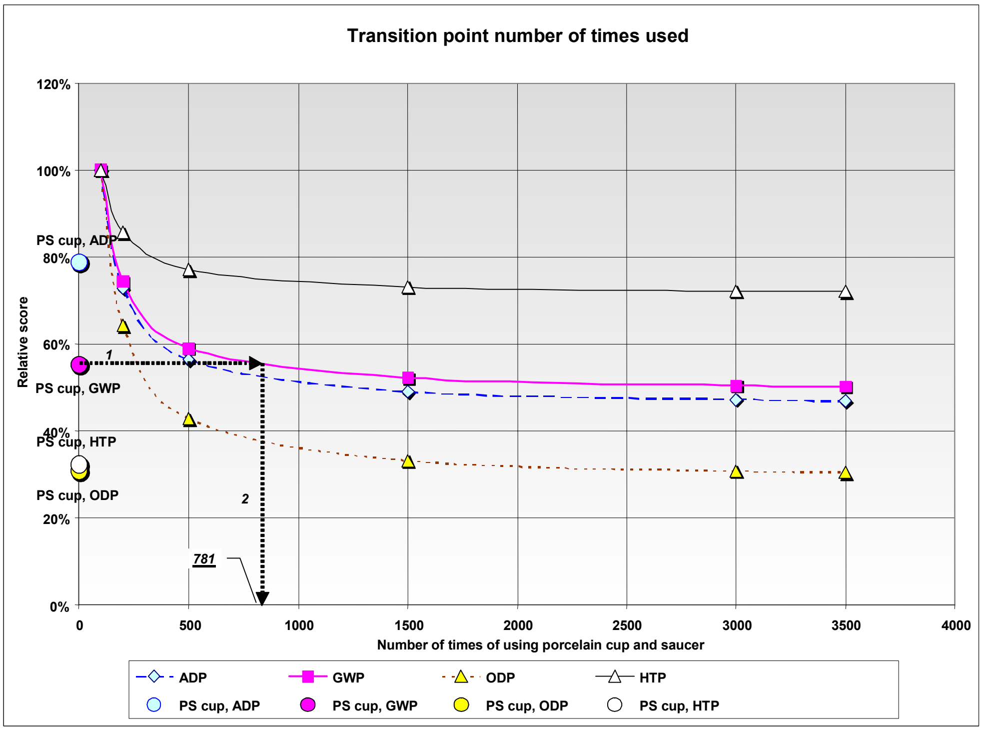

Figure 33 *Transition point for number of times use of reusable porcelain cup and saucer compared with the disposable polystyrene cup for ADP, GWP, ODP and HTP as examples of the effect categories. The polystyrene cup is positioned on the zero point of the x-axis. For the porcelain cup and saucer, the highest possible value per effect category considered is set at 100%. The transition point can be read off the graph by proceeding horizontally to the right from the figure for the disposable PS cup until the curve for the same effect category for the reusable porcelain cup and saucer is intersected (arrow 1 for example GWP). From this point, the value goes down perpendicularly; the value of the transition point (781) can then be read off the x-axis (arrow 2 for example GWP).*

Part II; not in conformity with the ISO 14040 and ISO 14044 standards

6. Aggregation of environmental effects

6.1 Shadow costs

The shadow costs express the environmental burden of a product system in a monetary unit: the Euro [34], [35]. The shadow costs are based on the shadow price per environmental effect category under the CML2 method (see Table 36). With the aid of the shadow price method, various environmental effect categories can easily be added together so that systems can be simply compared with each other. The shadow price also has the advantage that it dovetails with the use of market-conforming instruments.

The shadow price is based per effect category (GWP, HTP, etc.) on the emission reduction objectives for the substances covered by that category and on the cost of emission reduction measures that must be incurred per unit in order to achieve the objective. The shadow price is now the price per unit of emission reduction for the most expensive measure still to be introduced to achieve the objective.

The ISO standards [28] do not allow weighting for comparative public studies. ISO defines weighting as the process of converting indicator results of different impact categories by using numerical factors based on value-choices. The main issue in not allowing weighting is the use of value-choices. Of course policy goals **are** value-choices, but they are accepted value-choices in our democratic system. The use of shadow prices could be seen as the weighting method which is close to conformity with the main goal of ISO scientifically and value-free LCA results.

The contents of this chapter are in sensu stricto not in conformity with the ISO standards for comparative assertions disclosed to the public.

Table 36 Shadow prices per environmental effect category, as used in this report.

Effect category	Unit	Shadow price [€/kg eq.]	Source
ADP	Sb eq	0	[34]
AP	SO_2 eq	4	[35]
EP	PO_4^{3-} eq	9	[35]
FAETP	1.4-DCB eq	0.04	[34]
GWP	CO_2 eq	0.05	[35]
HTP	1.4-DCB eq	0.08	[34]
MAETP	1.4-DCB eq	0.0001	[34]
ODP	CFC11 eq	30	[35]
POCP	C_2H_2 eq	2	[35]
TETP	1.4-DCB eq	1.3	[35]

The shadow cost of e.g. the disposable polystyrene coffee cup is calculated by multiplying the quantity of equivalents found for each environmental effect category by the shadow price. The aggregated results of this calculation for all environmental effect categories then provide the total shadow costs.

An example of calculating the total shadow costs of a product system appears in Table 37. The shadow costs are calculated here on the basis of the values from the environmental profile of the reusable porcelain cup and saucer (see Table 11) and the shadow price for each effect category.

Table 37 Calculation of the shadow costs per environmental effect category of the reusable porcelain cup and saucer.

Effect category	Shadow price [€/kg eq.]	Effect [kg eq.]	Schadow costs [€]
ADP	0	8.15E-02	€ 0.00
GWP	0.05	1.17E+01	€ 0.59
ODP	30	5.42E-07	€ 0.00
HTP	0.08	4.36E+00	€ 0.35
FAETP	0.04	1.64E+00	€ 0.07
MAETP	0.0001	8.68E+03	€ 0.87
TETP	1.3	1.92E-01	€ 0.25
POCP	2	2.95E-03	€ 0.01
AP	4	7.34E-02	€ 0.29
EP	9	1.16E-02	€ 0.10
Total			**€ 2.52**

A more detailed description of the determination of shadow prices appears in Chapter 2 of the TNO report [31]. This chapter is appended as Annex 3.

6.2 Reusable porcelain cup and saucer

The shadow costs (€ 2.52) of the reusable porcelain cup and saucer are almost entirely (98%) determined by the user stage (see Table 38). The other stages make a negligible contribution.

Table 38 Shadow costs of the reusable porcelain cup and saucer per life stage.

Life stages	Shadow costs
1 Production of raw materials, porcelain	€ 0.00
2 Production of cup & saucer	€ 0.03
3 Use of cup & saucer	€ 2.48
4 Porcelain collection	€ 0.001
5 Porcelain waste processing	€ 0.002
Transportation	€ 0.01
Total	**€ 2.52**

The composition of the shadow costs can be regarded not only per life stage but also broken down according to the effect categories (GWP, HTP, etc.). The results shown in Figure 34 indicate that the greenhouse effect (GWP) and marine ecotoxicity (MAETP) are the highest contributory effect categories in the case of the reusable porcelain cup and saucer.

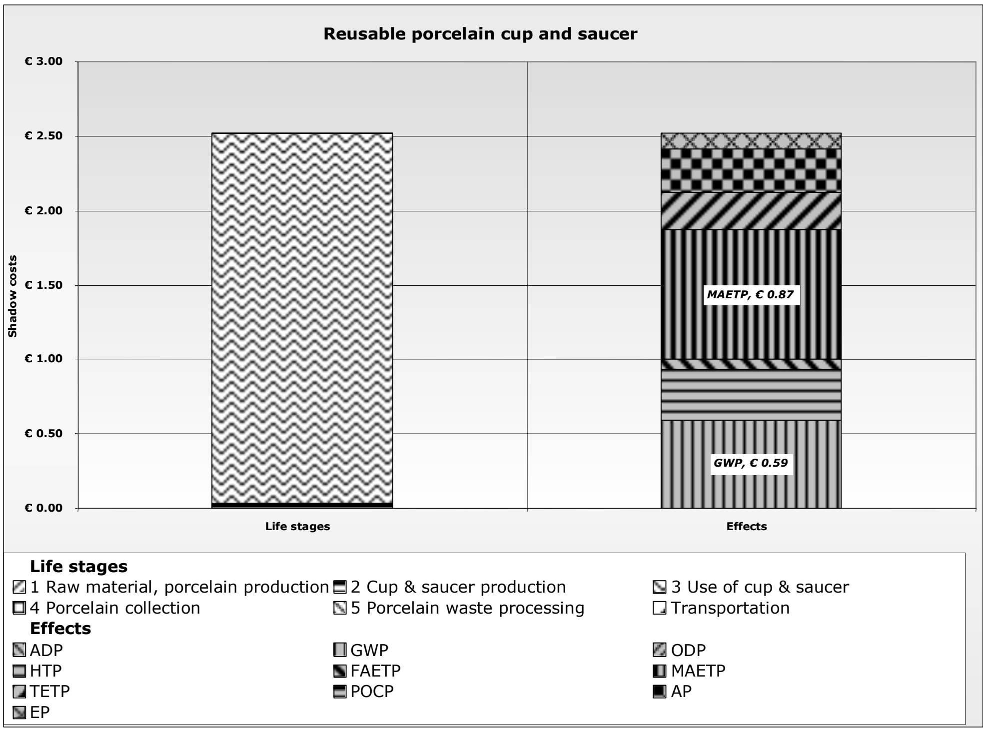

Figure 34 Composition of shadow costs per life stage and per effect category of the reusable porcelain cup and saucer.

6.3 Reusable earthenware mug

The shadow costs (€ 4.67) of the reusable earthenware mug are determined almost entirely by the user stage (see Table 39). These costs are clearly higher than those of the reusable porcelain cup and saucer during the user stage. Washing up a reusable earthenware mug requires more energy than washing up the reusable cup and saucer in a professional dishwasher. The other stages make a negligible contribution.

Table 39 Shadow costs of the reusable earthenware mug per life stage.

Life stages	**Shadow costs**
1 Raw material production	€ 0.00
2 Earthenware mug production	€ 0.01
3 Use of earthenware mug	€ 4.65
4 Earthenware collection	€ 0.001
5 Earthenware waste disposal	€ 0.001
Transportation	€ 0.001
Total	**€ 4.67**

As with the reusable porcelain cup and saucer, the effect categories MAETP and GWP make the greatest contribution in the case of the earthenware mug, at 33% and 25% respectively, see Figure 35.

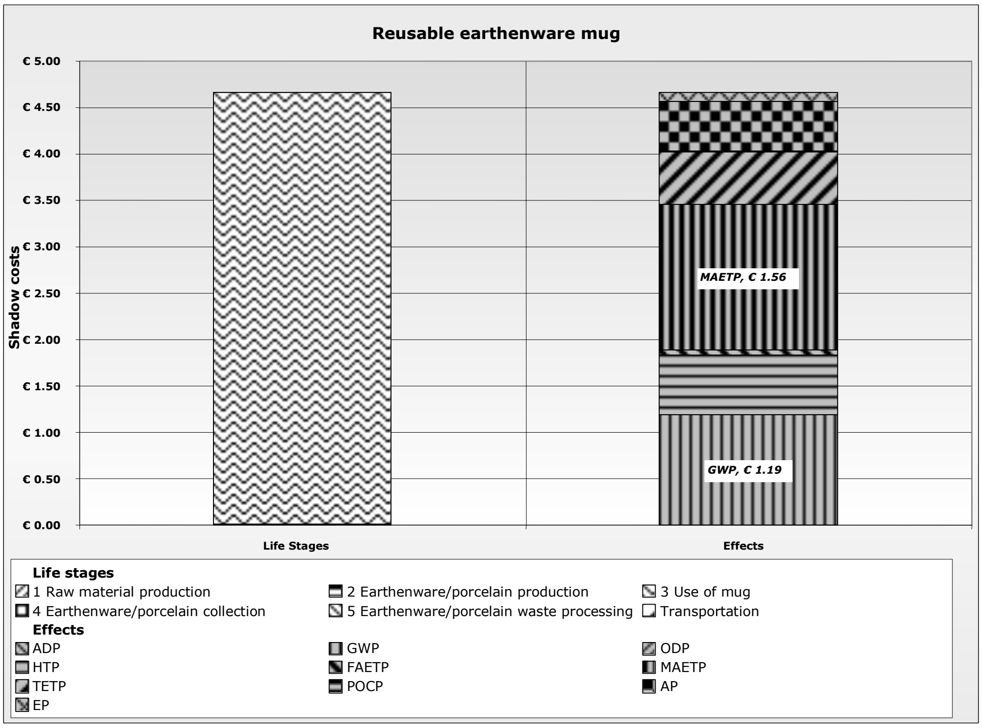

Figure 35 Composition of shadow costs per life stage and per effect category of the reusable earthenware mug.

6.4 Disposable polystyrene cup

The total shadow costs of € 1.42 for the disposable polystyrene cup is largely determined by the production of polystyrene and that of the cup itself (see Table 40). The end of life stage, which comprises collection of the used cups, recycling of the cup and processing of the waste, produces a net negative shadow cost. Negative shadow cost means that an advantage is obtained for the environment. See Figure 13 and paragraph 4.4 for a further explanation of this favourable effect.

Table 40 Shadow costs of the disposable polystyrene cup per life stage.

Life stages	Shadow costs
1 PS production	€ 1.01
2 Cup production	€ 0.36
3 Use	€ 0.00
4 PS cup collection	€ 0.26
5a Cup recycling	-€ 0.29
5b Waste processing	€ 0.00
PS Transportation	€ 0.08
Total	**€ 1.42**

The effect categories that contribute the most (see Figure 36) are again the greenhouse effect (GWP) and the marine ecotoxicity (MAETP). They contribute 44% and 17% respectively.

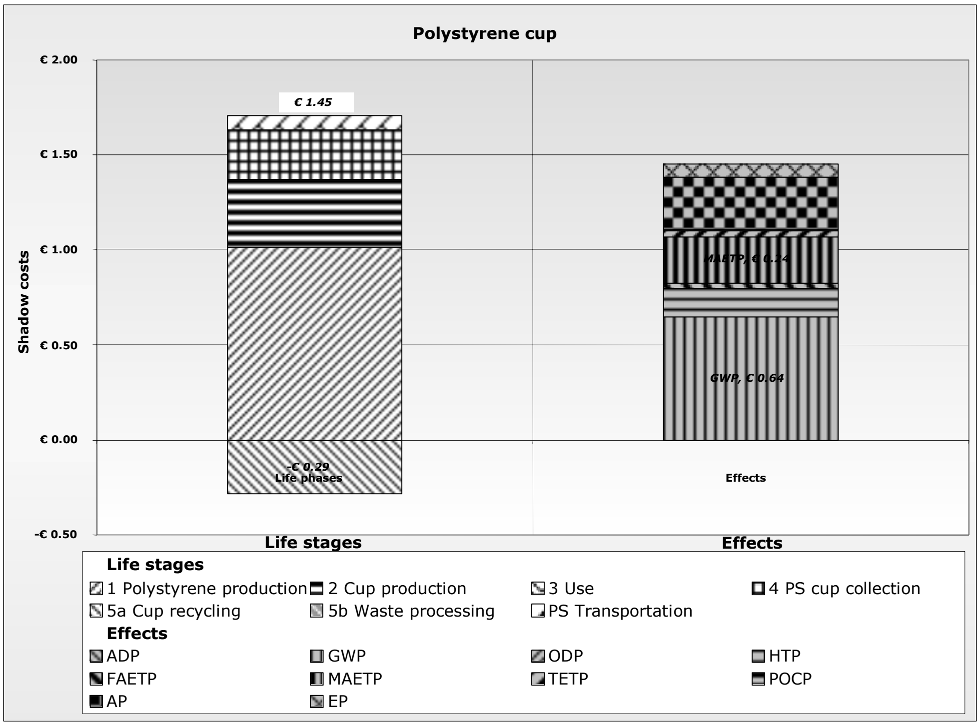

Figure 36 Composition of shadow costs per life stage and per effect category of the disposable polystyrene cup.

6.5 Disposable polystyrene insert cup

The production of the polystyrene and that of the insert cup from this polystyrene, at 67% and 24% respectively, determine the greater part of the total shadow costs (€ 1.01) of the disposable polystyrene insert cup (see Table 41).
Recycling the disposable polystyrene insert cup has a favourable effect and reduces the shadow costs by over 10%. The effect of the cup holder (production, use, collection and waste processing) on the shadow costs is negligible.

Table 41 Shadow costs of the disposable polystyrene insert cup per life stage.

Life stages	Shadow costs
1 PS Production	€ 0.68
2a Insert cup production	€ 0.24
2b Cup holder production	€ 0.01
3 Use of insert cup	€ 0.00
4a Insert cup collection	€ 0.17
4b Cup holder collection	€ 0.00
5a Insert holder recycling	-€ 0.19
5b Cup holder waste processing	€ 0.00
PS transportation	€ 0.08
Total	**€ 1.01**

The effect categories contributing the most to the shadow costs are GWP and MAETP, accounting for 45% and 16% of the total shadow costs (see Figure 37).

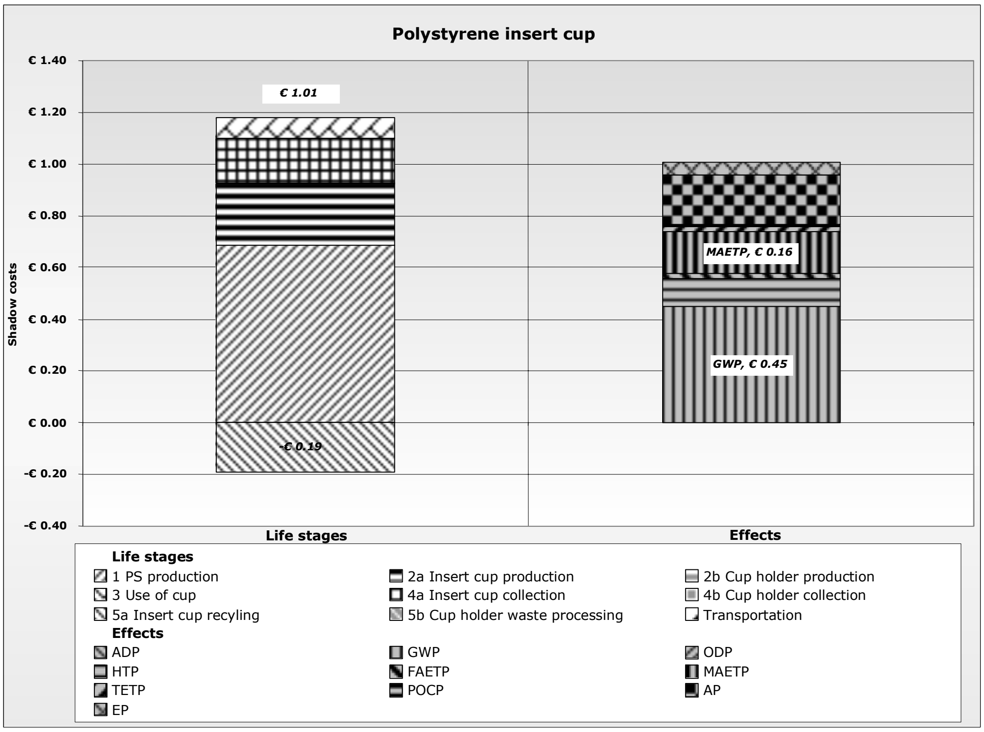

Figure 37 Composition of shadow costs per life stage and per effect category of the disposable polystyrene insert cup.

6.6 Disposable paper cup

The production of the PE coated cardboard accounts for a very large part (96%) of the total shadow cost (€ 0.85) of the disposable paper cup (see Table 42 and Figure 38). Waste processing of the cardboard , whereupon the cup is incinerated in an MSWI with energy recovery, reduces the shadow price by € 0.27.

Table 42 Shadow costs of the disposable paper cup per life stage.

Life stages	Shadow costs
1 Cardboard production	€ 0.82
2 Paper cup production	€ 0.06
3 Use of cup	€ 0.00
4 Cup collection	€ 0.05
5a Pre-consumer cardboard recycling	€ 0.09
5b Cardboard waste processing	- € 0.27
Board transportation	€ 0.10
Total	**€ 0.85**

The environmental effect categories with the greatest bearing on shadow costs are the greenhouse effect (GWP) and human toxicity (HTP). These determine 22% and 28% respectively of the total; see Figure 38.

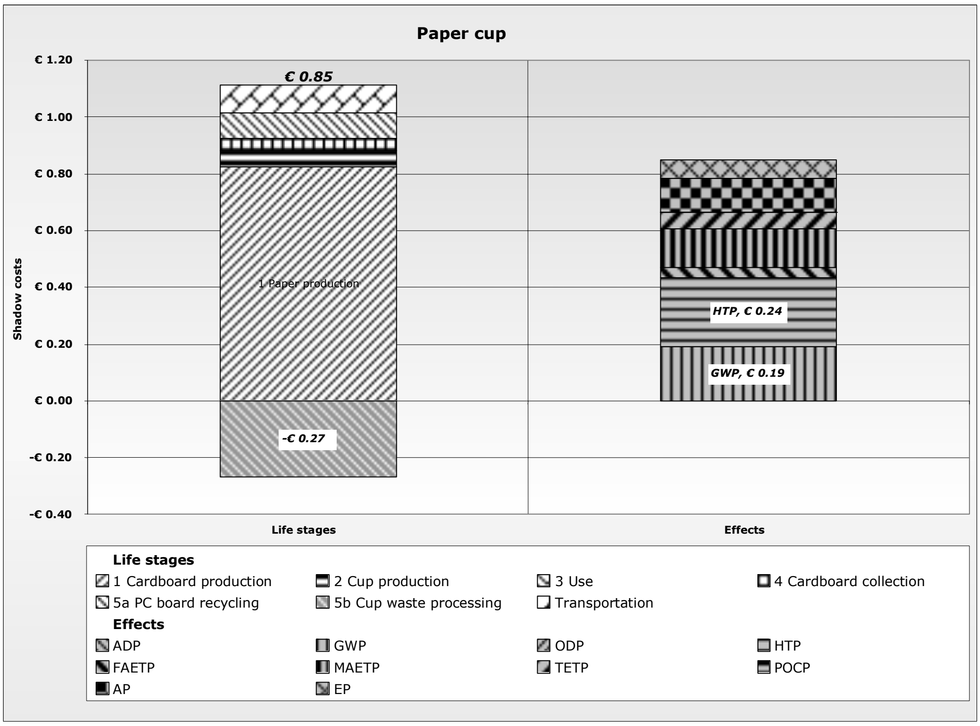

Figure 38 Composition of shadow costs per life stage and per effect category of the disposable paper cup.

6.7 Comparison of (coffee) drinking systems

A comparison of the coffee and other drinking systems examined on the basis of shadow costs (see Figure 39) shows that the reusable earthenware mug is the system with the highest environmental burden at a shadow cost of € 4.67. This is followed by the reusable porcelain cup and saucer (€ 2.52). The differences as against the other systems are always greater than 20% for these systems. Then follows the disposable polystyrene cup (€ 1.45) and then the PS insert cup (€ 1.01). The disposable paper cup (€ 0.85) performs better than the other systems.

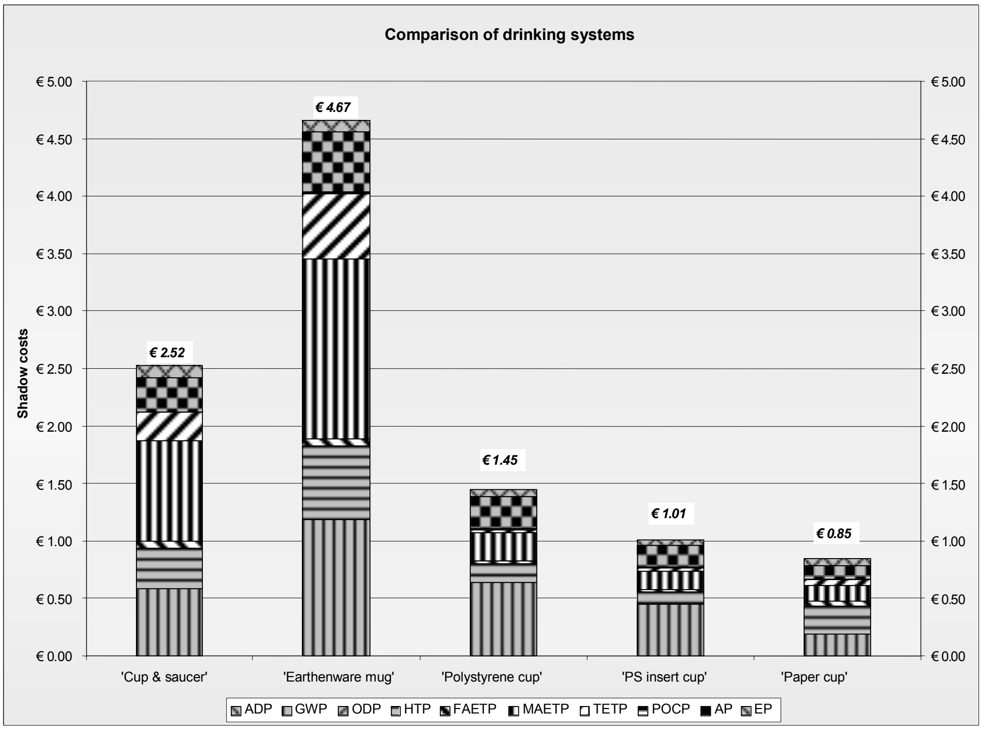

Figure 39 Comparison of the five drinking systems investigated on the basis of the shadow prices method.

6.8 Sensitivity analyses

The results of the sensitivity analyses are set out in this section in shadow costs form terms. The analyses will be discussed in less detail than was already done in Chapter 5 above. Reference may be made to this chapter, too, for details of the scenarios examined.

6.8.1 Number of times reusable porcelain cup and saucer are used

The reusable porcelain cup and saucer are relatively insensitive to changes in the number of times they are used. Reducing these by a factor of 2 (from 3,000 to 1,500 times used) increases the shadow costs by 1% only (see Table 43).

Table 43 Sensitivity of shadow costs to a change in the number of times used of the reusable porcelain cup and saucer. The basic scenario has in this case been set at 100%.

System	Value
Cup & saucer (used 3000 times)	100%
Cup & saucer (used 1500 times)	101%
Cup & saucer (used 1000 times)	103%
Cup & saucer (used 500 times)	107%

Changes in the life time of the cup and saucer produce no differences in ranking between the systems (see Figure 40). The reusable porcelain cup and saucer maintain their original position in the ranking in accordance with the basic scenario.

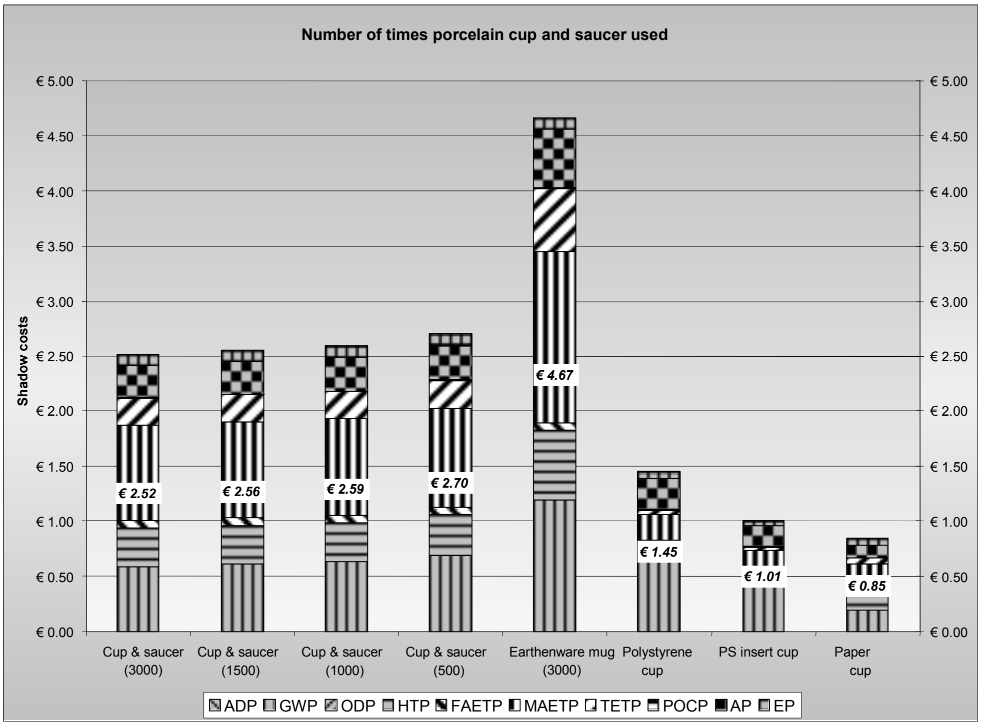

Figure 40 Influence of the variation in the number of times the reusable porcelain cup and saucer are used on shadow costs. In the basic scenario, they are discarded after 3000 times used. The figure under "Cup and saucer (1500)" indicates that the porcelain cup and saucer is discarded after being used 1500 times.

6.8.2 Cleaning frequency of reusable drinking systems

Cleaning reusable systems at a lower frequency clearly reduces the shadow costs. Reducing the cleaning frequency nearly always affects the shadow costs; see Table 44.

Table 44 Sensitivity of shadow costs to a change in cleaning frequency of reusable drinking systems. The basic scenario has in this case been set at 100%.

Drinking system	Value
Porcelain cup and saucer	100%
Porcelain cup and saucer (2) [1]	51%
Porcelain cup and saucer (4.5) [2]	23%
Earthenware mug	100%
Earthenware mug (2)[1]	50%
Earthenware mug (4.5)[2]	22%

1 Cleaning after being used twice.
2 Cleaning after being used 4.5 times.

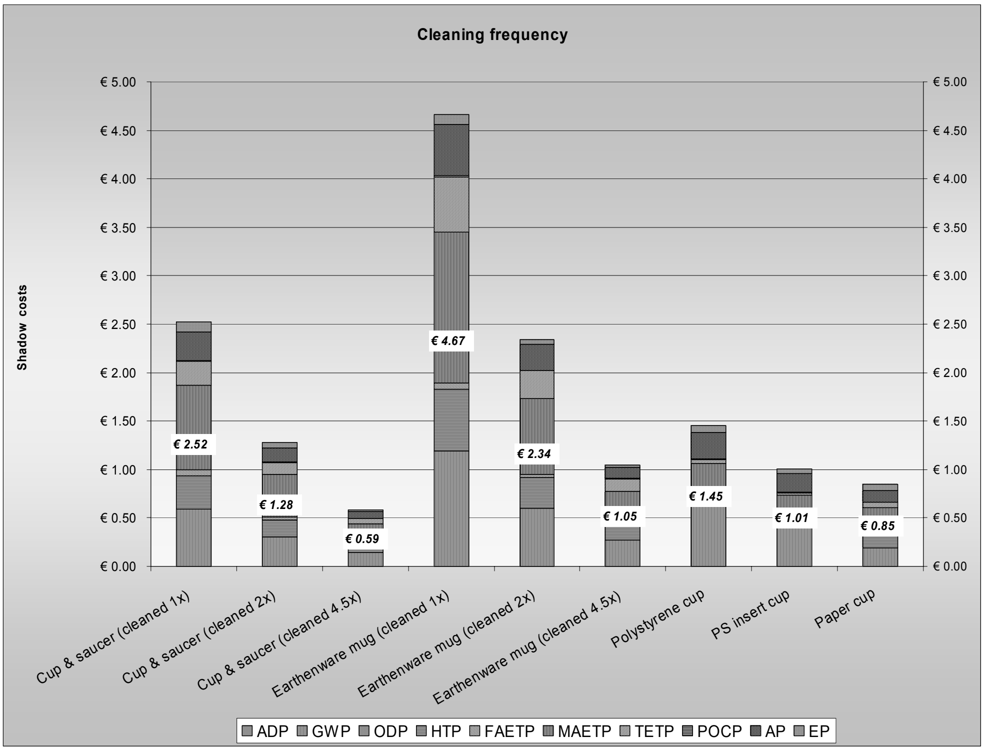

Figure 41 Influence of the change in cleaning frequency of the reusable systems on the shadow costs. In the basic scenario, the reusable systems are cleaned each time after use. For the sensitivity analysis, (cleaned 2x) means cleaned each time after being used twice, (cleaned 4.5x) cleaned after being used 4.5 times on average.

With the lowest cleaning frequency, the reusable systems are the best performing; they have the lowest shadow costs (see Figure 41). On cleaning after each second use, the reusable porcelain cup and saucer show lower shadow costs than the disposable polystyrene and paper drinking systems.

6.8.3 Energy use of dishwasher

During the user stage of the reusable porcelain cup and saucer, the energy consumption of the dishwasher determines the environmental burden of this system. The change in this energy use clearly influences the shadow costs (see Table 45).

Table 45 Sensitivity of shadow costs to a change in energy consumption of the dishwasher for cleaning the reusable porcelain cup and saucer. The basic scenario has in this case been set at 100%. The "washer 70" scenario indicates the effect of energy use at 70% of the basic scenario; "washer 130" a 130% use.

Cup & saucer	Cup & saucer (washer 70)	Cup & saucer (washer 130)
100%	77%	123%

In the scenario where the dishwasher uses 70% of the energy of the basic scenario, the position of the reusable porcelain cup and saucer does not change when compared with disposable systems (see Figure 42).

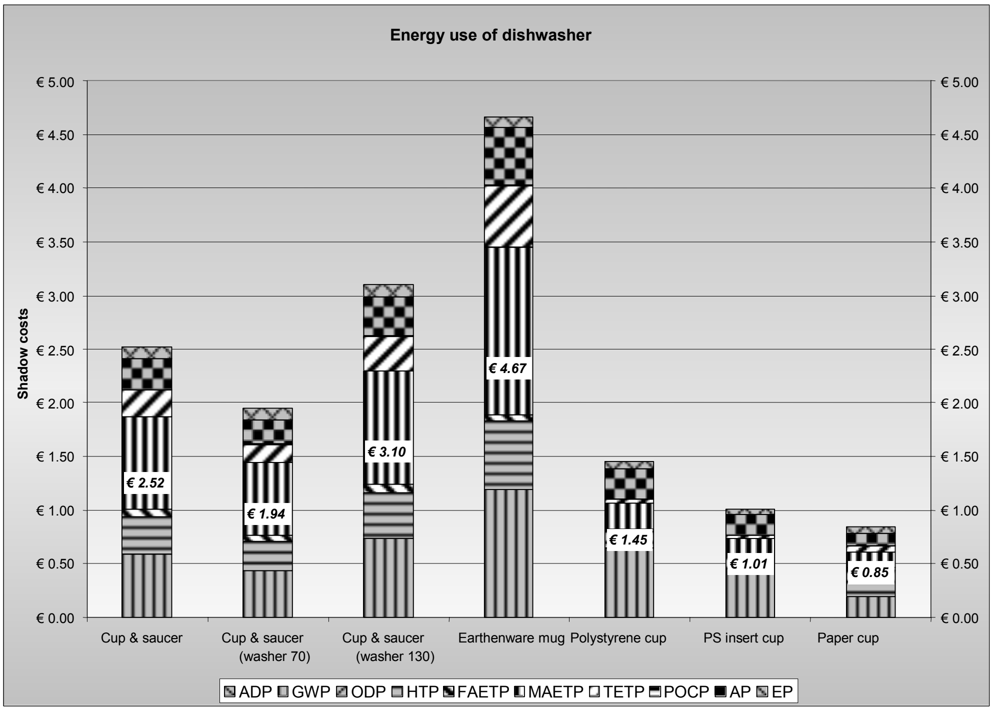

Figure 42 *Influence of the change in energy consumption of the dishwasher for cleaning the reusable porcelain cup and saucer on shadow costs. The addition "washer 70" indicates an energy consumption of 70% of the basic scenario; "washer 130" 130% use.*

6.8.4 Water and energy consumption

The use of the data for cleaning the reusable cup & saucer from the TAUW study [1] results in an increase in shadow costs to 125% of the value under the basic scenario (see Figure 43). The result of this increase is that use of the reusable porcelain cup and saucer produces yet more environmental impact when compared with disposable systems.

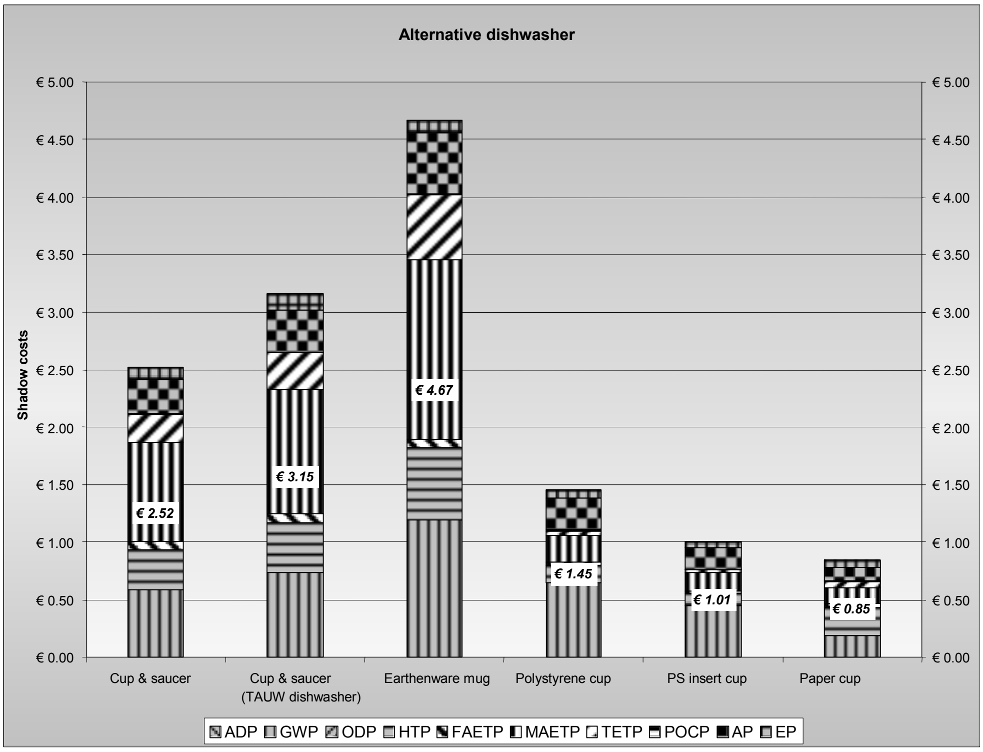

Figure 43 *Influence of the change in environmental data for the dishwasher for the reusable porcelain cup and saucer on shadow costs. "TAUW dishwasher" indicates the scenario where the dishwasher data from [1] are used.*

The reusable earthenware mug is the system with the highest shadow costs (€ 4.67) according to the basic scenario. The user stage (cleaning) determines virtually the entire shadow cost (see 6.3). The effect of a changed method of cleaning is determined by the following sensitivity analyses.

A change in the quantity of hot water used per cleaning from 0.4 litres to 0.2 and 0.6 litres results in a proportional change in shadow costs (see Table 46). Cleaning with cold water[1] instead of hot water produces a very sharp reduction in the shadow costs to 2% of that of the basic scenario.

Table 46 *Sensitivity of shadow costs to a change in the quantity and temperature of the water for cleaning the reusable earthenware mug. The basic scenario has in this case been set at 100%.*

System	Value
Earthenware mug	100%
Earthenware mug (0.2 l)	50%
Earthenware mug (0.6 l)	150%
Earthenware mug (cold cleaning)	2%

1 This cannot really be recommended for clear hygienic reasons (bacteria)! [37].

Changing the cleaning method produces differences in ranking for the earthenware mug (see Figure 44). When cleaning the reusable earthenware mug with 0.2 l hot water shadow costs (€ 2.34) are comparable to that of the reusable porcelain cup and saucer (€ 2.52). Cold cleaning of the reusable earthenware mug makes this in this case the drinking system with the lowest shadow costs (€ 0.10).

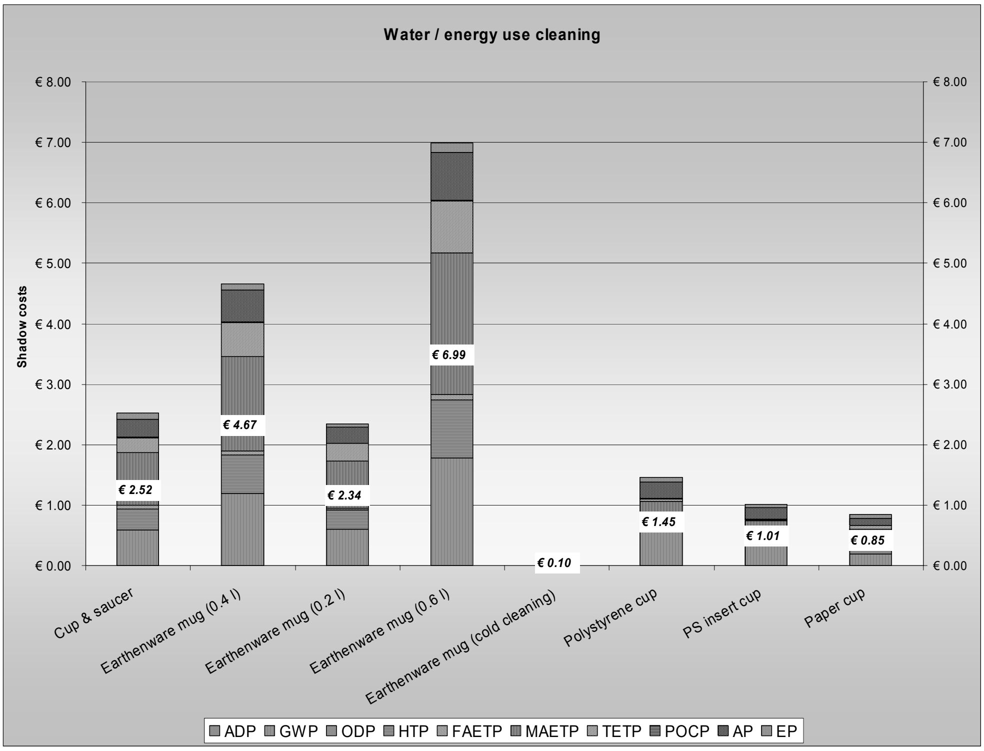

Figure 44 Influence of a change in the quantity of water (hot) for washing up the reusable earthenware mug. Under the basic scenario 0.4 l hot water is used. Alternatives are: '0.2 l' cleaning with 0.2 l hot water, '0.6 l' cleaning with 0.6 l hot water and "cold clean" cleaning with cold water.

6.8.5 Variation in cup weight of disposable systems

A change in the weight of disposable cups directly affects environmental impact (see 5.6) and consequently also the shadow costs (see Figure 45).

The change in disposable cup weight does not affect the ranking between the reusable systems and the single use systems.

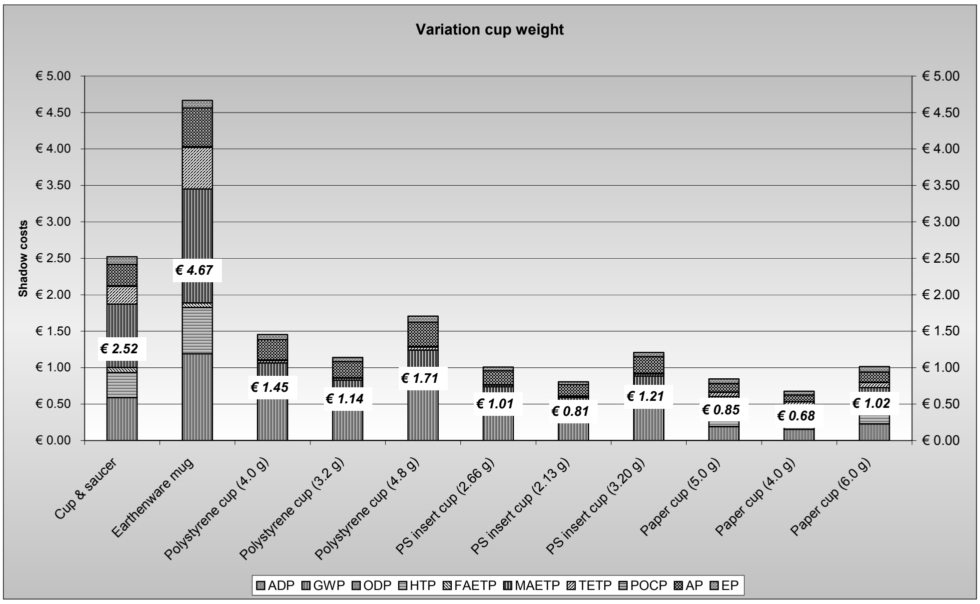

Figure 45 Influence of a change in the weight of the disposable cup. Under the basic scenario, the polystyrene cup weighs 4.0 grams, the PS insert cup 2.66 grams and the paper cup 5.0 grams. The adjusted weight is shown in brackets.

In addition to the disposable polystyrene vending cup and the disposable PS insert cup, the disposable PS drinking cup is also used (2.8-3.2 gram). Because its weight lies between that of the disposable polystyrene vending cup and that of the PS insert cup, the environmental performance of a disposable PS drinking cup will produce a score between that of the disposable PS vending cup and that of the disposable PS insert cup.

6.8.6 Number of times disposable systems are used

Because the cups themselves or their production importantly influence drinking systems, using the cup more often has a strong bearing on the shadow costs. Using a disposable cup twice instead of once therefore reduces the shadow costs to 50% of the original value (see Table 47).

Table 47 Sensitivity of the shadow costs to using disposable cups more often. The basic scenario in this case is set at 100%. Deviations may occur through rounding off.

System	Value
polystyrene cup	100%
polystyrene cup, used twice	50%
polystyrene cup, used 4.5 times	22%
PS insert cup	100%
PS insert cup, used twice	50%
PS insert cup, used 4.5 times	23%
Paper cup	100%
Paper cup, used twice	50%
Paper cup, used 4.5 times	22%

For the disposable polystyrene cup, some positive shifts occur on repeated use (see Figure 46). The disposable polystyrene cup in this case scores higher than the disposable PS insert cup and the disposable paper cup, which is used only once. However, the same conclusion also applies to the two other disposable systems.

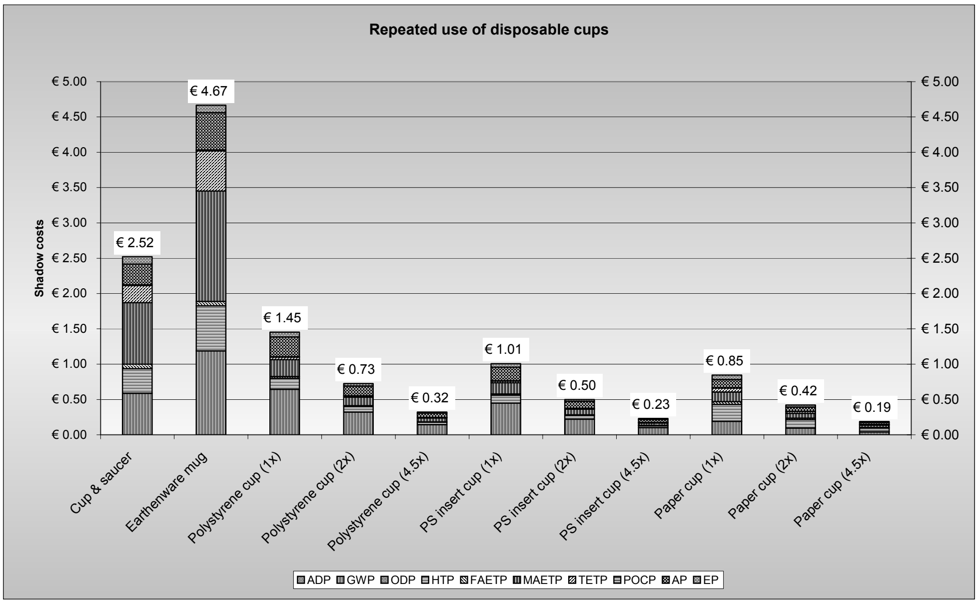

Figure 46 Influence of repeated use of disposable cups on shadow costs. Under the basic scenario the disposable cups are used only once. Alternatives are: "2x" used twice; "4.5x" used 4.5 times.

6.8.7 Allocation based on the economic value of recycled plastics

Under the basic scenario, 50% of environmental impact by virgin PS is avoided on recycling of polystyrene obtained from used disposable cups, based on the economic value of the recyclate. An allocation was made in the sensitivity analysis of 65% and 90% of the economic value of the virgin material.

Increasing the allocation of the economic value from 50% of virgin PS avoided to an economic value of 90% virgin PS avoided results in a reduction of the shadow costs to 79% of the initial situation (see Table 48).

Table 48 Sensitivity of shadow costs to the allocation of the economic value of the virgin polystyrene production avoided by recycling of the disposable PS cups. The basic scenario is set at 100%.

System	Value
Polystyrene cup	100%
Polystyrene cup, 65% allocation	89%
Polystyrene cup, 90% allocation	73%
PS insert cup	100%
PS insert cup, 65% allocation	90%
PS insert cup, 90% allocation	74%

On the changes in the allocation shown, no changes occur in sequence compared with the position under the reusable systems (see Figure 47).

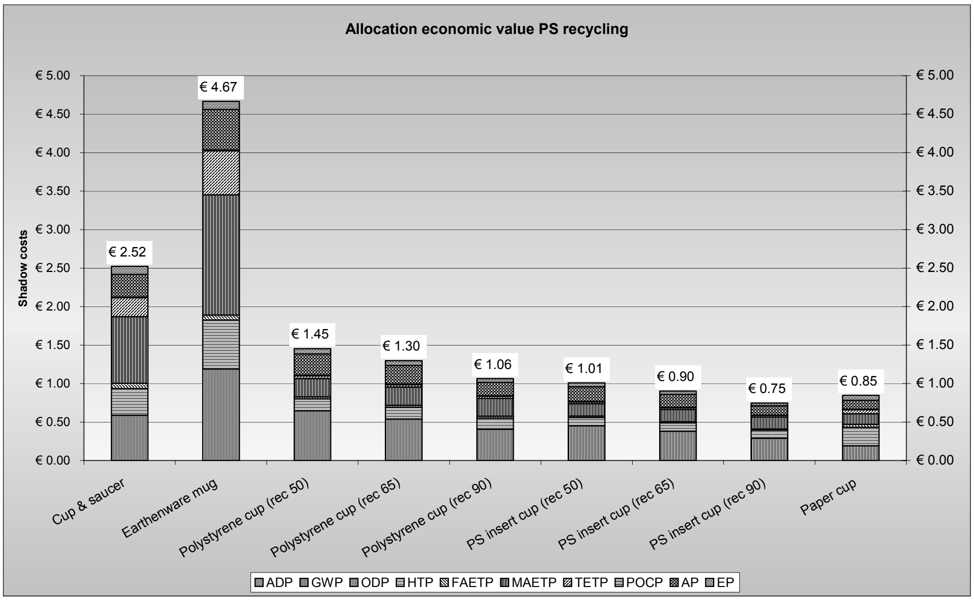

Figure 47 Influence of allocation of the economic value of the polystyrene production avoided by recycling of used disposable PS cups on shadow costs. In the basic scenario 50% of the production avoided is allocated to recycling. Alternatives are: "rec 65" 65% allocation; "rec 90" 90% allocation.

6.8.8 European post consumer waste scenario

The paper cup is the most sensitive of the single use systems to changing the base waste scenario to that of the EU-15 (see Table 49). Instead of being incinerated (with energy recovery) the paper cup is now largely landfilled (78%) and the part that is incinerated is less energy efficient. This leads to a significant reduction of the end-of-life bonus for avoided energy production.

Table 49 Sensitivity of shadow costs to the changing of the base waste scenario to that of the EU-15 waste scenario for post consumer waste. The base scenario is set at 100%.

System	Value
Polystyrene cup	100%
Polystyrene cup, EU-15 waste scenario	108%
PS insert cup	100%
PS insert cup, EU-15 waste scenario	103%
Paper cup	100%
Paper cup, EU-15 waste scenario	131%

The change in the waste scenario results in a change in the ranking of the systems. In the base case the paper cup was the system with the lowest shadow costs; the EU-15 waste scenario shows the PS insert cup with a slightly better performance (see Figure 48). The EU-15 waste scenario does not lead to a change in the ranking of the single use cups compared to the reusable cup and saucer an the reusable earthenware mug.

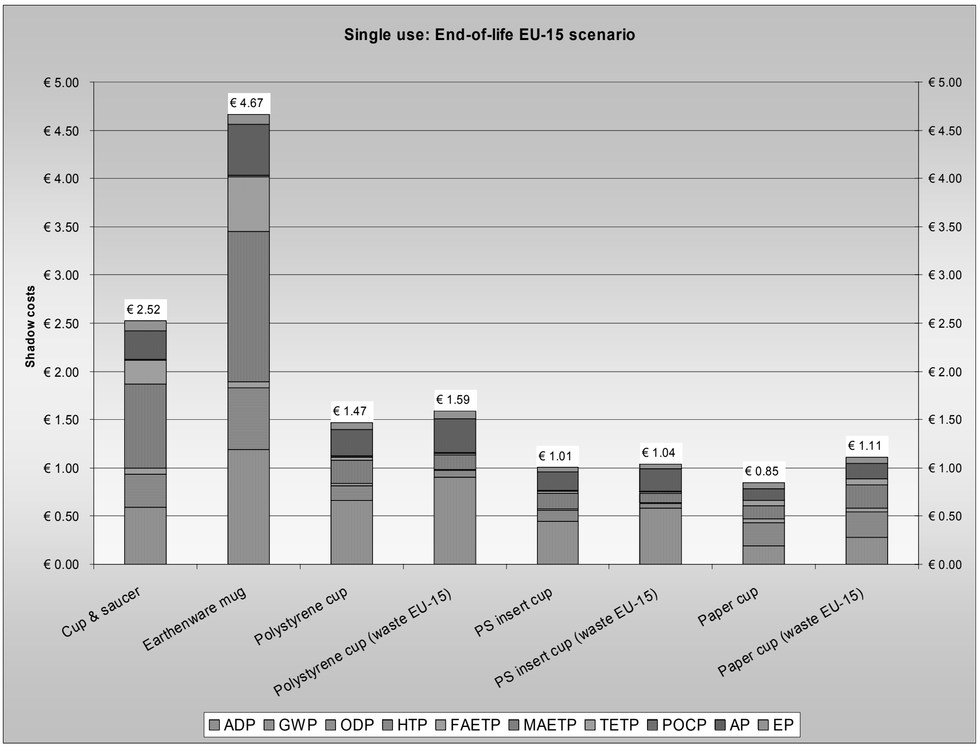

Figure 48 *Influence of the EU-15 waste scenario for the single use cups. In the basic scenario the polystyrene cups are recycled while the paper cups are incinerated. In the EU-15 waste scenario the cups go mostly to landfill and the rest is incinerated.*

6.8.9 Alternative end-of-life routes for disposable polystyrene (insert) and paper cups

When the environmental burden is expressed in shadow costs, changing the end-of-life route from recycling used disposable PS cups to incineration in an MSWI has little if any effect. Although clear differences arise in the shadow costs, the value for GWP increases substantially while the values for toxicity related effects are reduced (see 5.9), the net shadow costs remains (virtually) equal (see Table 50 and Figure 49).

Table 50 Sensitivity of the values of shadow costs for the end-of-life scenario of the disposable PS (insert) and paper cups. The basic scenario has in this case been set at 100%.

System	Value
Polystyrene cup	100%
Polystyrene cup (MSWI)	98%
Polystyrene cup (sub-coal)	53%
PS insert cup	100%
PS insert cup (MSWI)	96%
PS insert cup (sub-coal)	51%
Paper cup	100%
Paper cup (sub-coal)	52%

If used disposable PS cups are used for the production of sub-coal instead of being recycled as a material, shadow costs are reduced (see Table 50). A reduction in shadow costs as determined by GWP, HTP and AP, in particular, results in a reduction in total shadow costs (see Figure 49). The reduction in shadow costs is also seen for the paper cup. Here a negative value for GWP and a strongly reduced value for AP are most prominent.

The disposable cups will score clearly better on application of the sub-coal route.

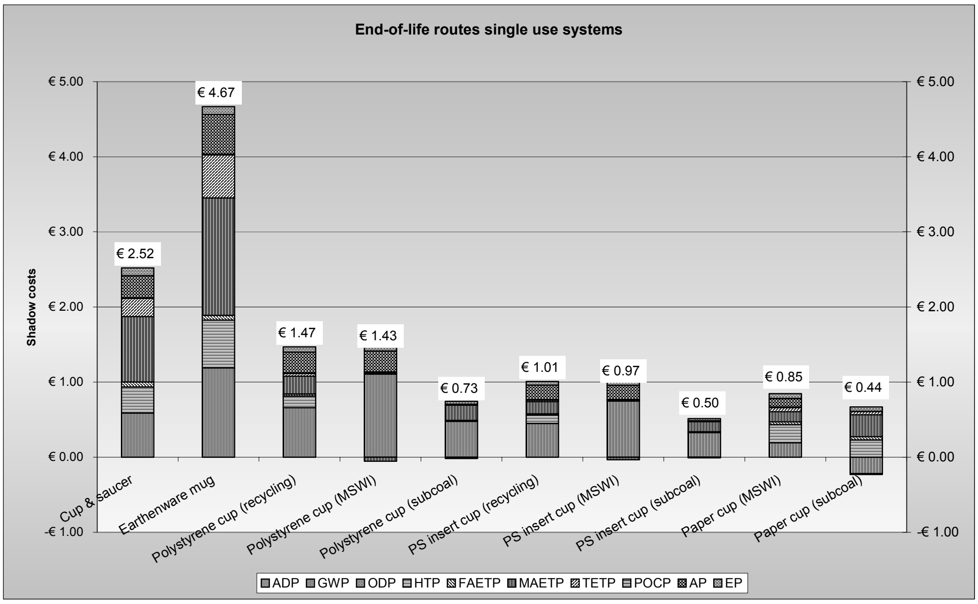

Figure 49 Influence of the choice of end-of-life scenario for disposable PS (insert) and paper cups. Under the basic scenario, the disposable PS (insert) cups are recycled, while the paper cups are incinerated in an MSWI.

6.8.10 Summary of the sensitivity analyses

The results of the sensitivity analyses based on the shadow cost method demonstrate that the reusable drinking systems are very sensitive to the method and frequency of cleaning and energy and detergent consumption when cleaned. If the reusable porcelain cup and saucer and the reusable earthenware mug are not cleaned after each use, they will perform better in terms of environmental impact. In that case, the reusable systems may perform better than the disposable drinking systems. On the other hand, if they are used more often, the disposable cups continue to perform better than the reusable drinking systems.

Reducing the weight of disposable cups also results directly in a reduction in the integral burden on the environment. The way in which the end-of-life route for disposable polystyrene and paper cups is pursued affects the integral environmental burden. Use of the cups as a sub-coal fuel in power plants has a favourable effect on the environmental performance.

7. Conclusions and recommendations (Part I and Part II)

7.1 Main conclusion

It has become clear from the present study that the way in which the individual user uses a reusable or disposable coffee cup strongly determines the environmental burden of the overall coffee or other drinking system. For the reusable porcelain cup and saucer and the reusable earthenware mug, cleaning the cup is decisive as to environmental impact. The frequency of cleaning and energy consumption per cleaning are crucial in this case. Because the user has plenty of freedom here, the actual environmental impact is ultimately therefore strongly user-related.

For disposable systems, too, the user largely determines the ultimate environmental burden by the way he uses the polystyrene cup, polystyrene insert cup or paper cup repeatedly or only once.

The question “What is better for the environment, drinking coffee out of a disposable or a reusable cup?” can therefore only be answered on the basis of the specific operating situation. The results of the comparisons made, by means of the shadow prices method[1], clearly point in the direction that disposable (coffee) drinking systems being the least environmentally burdening.

7.2 Other conclusions

Reusable systems
For reusable systems, cleaning the porcelain cup and saucer and the earthenware mug, with a contribution between 90 and 100%, is crucial to the environmental burden of the coffee or other drinking systems. The life time of the porcelain cup and saucer, which in the sensitivity analysis varied between 500 and 3000 times use, influences the environmental profile of this coffee or other drinking systems only subordinately.

Disposable systems
For the disposable systems, the production of the necessary raw materials and that of the cup used largely determine the environmental profile. In the case of the disposable polystyrene cup and the disposable polystyrene insert cup, recycling to PS regranulate, its incineration in a waste incineration plant or energy recovery, using sub-coal in a power plant, all have a clearly positive effect on the environmental profile of these coffee or other drinking systems.

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1 This method is strictly speaking not in conformity with the ISO standards.

In the case of energy recovery using sub-coal in a power plant, PS disposable and paper systems score better than the reusable systems. The sub-coal route is therefore strongly recommended as an alternative for the future.

7.3 Limitations of the study

An Life Cycle Impact Assessment (LCIA) cannot provide the sole basis of comparative assertion intended to be disclosed to the public of overall environmental superiority or equivalence, as additional information will be necessary to overcome some of the inherent limitations in the LCIA. Value-choices, exclusion of spatial and temporal aspects, threshold and dose-response information, relative approach, and the variation in precision among impact categories are examples of such limitations. LCIA results do not predict impacts on category endpoints, exceeding thresholds, safety margins or risks.

7.4 Recommendations

Which coffee or other drinking system is preferable from an environmental point of view can be ascertained for a specific operational situation only. The individual user in a working environment is advised to survey and evaluate his own operating situation before making a choice. Obtaining external advice can support a choice of this kind.

A second recommendation is the implementation of the sub-coal route for processing the post-consumer waste of the disposable polystyrene and paper drinking systems.

8. References

[1] VROM, 1991, Reusable versus Disposable. Een vergelijking van de milieubelasting van servies van polystyreen, papier/karton en porselein. Publikatiereeks produktenbeleid nr. 1991/2 (revised impression). Ministry of Housing, Spatial Planning and the Environment, Directorate-General for Environmental Protection.

[2] TAUW Infra Consult bv, 1992, "Recycling polystyrene (coffee) cups, sense or nonsense" TAUW R3184269.E01/PNG. Deventer, November 1992

[3] Lodder, G., 2006, comment by Mr. G. Lodder, Autobar Holland

[4] Ligthart, T.N. en Ansems, A.M.M., 2004, Eco-efficiency van retoursystemen van kunststof koffiebekers. TNO Report R2003/453

[5] Jansen, R., 2000, Weggooien of spoelen? Milieuvergelijking van eenmalige en meermalige kunststof glazen, gebruikt op evenementen. Ronald Jansen Milieuadvies

[6] Douwe Egberts Nederland, 2005, Open over duurzaamheid, Maatschappelijk Verslag Douwe Egberts Nederland FY04

[7] Guinée, J.B. et al, Life cycle assessment - an operational guide to the ISO standard, vol. I, II and III, Institute of Environmental Sciences – University of Leiden, May 2001. *August 2005 version, v 2.03*

[8] Huijbregts, M.A.J., 2000, Priority Assessment of Toxic Substances in the frame of LCA – draft, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, March 2000

[9] L. van Oers, A. de Koning, J.B. Guinée & G. Huppes, 2002, Abiotic resource depletion in LCA - Improving characterisation factors for abiotic resource depletion as recommended in the new Dutch LCA Handbook

[10] Ligthart et al, 2004, Declaration of Apeldoorn on LCIA of Non-Ferro Metals http://www.uneptie.org/pc/sustain/reports/lcini/Declaration%20of%20Apeldoorn_final.pdf

[11] Danish EPA, 2001, Environmental Impact of Packaging Materials, Revised version, August 2001

http://www.mst.dk/homepage/default.asp?Sub=http://www.mst.dk/waste/Pack-App3ProductSystems.htm

[12] NVZ, 2005, Producten voor de vaatwas. http://www.isditproductveilig.nl/was_en_reinigingsmiddelen/index.php?file_id=29

[13] Institut Fresenius, 1997, Ermittlung von Wasser- und Energieverbrauchdaten von Spülautomaten in gastronomischen Betrieben. Institut Fresenius 17-09-1977

[14] de Vos-Effting, S., 2005, comment by Mrs de Vos-Effting, Pré Consultants

[15] Hans-Jörg Althaus, Gabor Doka, Roberto Dones, Stefanie Hellweg, Roland Hischier, Thomas Nemecek, Gerald Rebitzer, Michael Spielmann, Rolf Frischknecht, Niels Jungbluth (Editors), 2003, Overview and Methodology; Data v1.01 (2003); ESU-services, Uster; ecoinvent report No. 1, Dübendorf, December 2003

[16] Winterhalter Gastronom AG, 2005, http://www.wihatec.ch/gallery/thumbnails_pics/wkt1000_vogelperspektive.jpg

[17] Korean Association of Machinery Industry, 2005?, Paper cup manufacturing plant. www.koami.or.kr

[18] Papstar, 2005, Catalogus Disposable Tableware And Packing Goods. http://www.papstar-katalog.de/

[19] Blankert, P., 2006, comment by Paul Blankert, Huhtamaki, Alf, Germany

[20] Jukkenekke, H.C. 2006, comment by H.C. Jukkenekke, St. Disposables Benelux

[21] VLCA, 2000, Achtergronddata voor de Bouw, een uitwerking in de vorm van een referentie, de VLCA database, TNO-MEP Report R2000/109

[22] Flemström, K. and Pålsson, A.-C., 2003, Introduction and guide to LCA data documentation using the CPM documentation criteria and the ISO/TS 14048 data documentation format. CPM Report 2003:3

[23] Jukkenekke, H.C., 2005, comment by H.C. Jukkenekke, Stichting Disposables Benelux

[24] Nuon, 2005, Nuon personal Energy Advice

[25] Inventum BV, ?, Kitchen boilers brochure

[26] StoraEnso, 2005, Product Selector: Cupforma Classic R PE. http://www.storaenso.com/CDAvgn/main/0,,1_-6224-13722-,00.html#

[27] ISO, 1998, ISO-14041 Environmental management - Life cycle assessment - Goal and scope definition and inventory analysis

[28] ISO, 2000, ISO-14042 Environmental management - Life cycle assessment - Life cycle impact assessment

[29] ISO, 2000, ISO-14043 Environmental management - Life cycle assessment - Life cycle interpretation 1. March 2000

[30] Eurostat, 2007, Municipal waste treatment, by type of treatment method. http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,39140985&_dad=portal&_schema=PORTAL&screen=detailref&language=en&product=SDI_MAIN&root=SDI_MAIN/sdi/sdi_pc/sdi_pc_eco/sdi_pc1210

[31] Eurostat, 2007b, Treatment of municipal waste. http://epp.eurostat.ec.europa.eu/portal/page?_pageid=1996,39140985&_dad=portal&_schema=PORTAL&screen=detailref&language=en&product=Yearlies_new_environment_energy&root=Yearlies_new_environment_energy/H/H1/H12/ddb14096

[32] Croezen, H.J., Bergsma, G.C., 2000, Subcoal milieukundig beoordeeld; Nagescheiden huishoudelijk kunststofafval in een kolencentrale vergeleken met biomassa, vergassing, verwerking in cementoven en MSWI; Publication number: 00.5498.21

[33] Schöen, L.A.A., Beekes, M.L., Tubergen, J. van, Korevaar, C.H., 2000, Mechanical separation of mixed plastics from household waste and energy recovery in a pulverised coal-fired power plant. http://www.apme.org/

[34] Harmelen, A.K. van, Korenromp, R.H.J., Ligthart, T.N., Leeuwen, Mw. S.M.H. van, Gijlswijk, R.N. van., 2004, Toxiciteit heeft z’n prijs. Schaduwprijzen voor (eco-)toxiciteit en uitputting van abiotische grondstoffen binnen DuboCalc, on behalf of Ministry of Transport, Public Works and Water Management, TNO Report R 2004/101. March 2004

[35] Soest, Jan Paul van, Hein Sas, Gerrit de Wit. Appels, peren en milieumaatregelen. Afweging van milieumaatregelen op basis van kosteneffectiviteit. CE, Delft. October 1997

[36] Plastics Europe, 2006, Ecoprofiles.
http://www.plasticseurope.org/content/default.asp?PageID=392#

[37] Hazard Analysis And Critical National Advisory Committee On Microbiological Criteria For Foods, 1997, Control Point Principles And Application Guidelines. Adopted August 14, 1997.
http://www.cfsan.fda.gov/~comm/nacmcfp.html#app-b

9. Abbreviations

Abbreviation	Meaning
ADI	Allowable Daily Intake
ADP	Abiotic mineral resources Depletion Potential
AP	Acidification Potential
BOD	Biological Oxygen Demand
CFC	Chloro-Fluoro Hydrocarbons
CML	Institute of Environmental Sciences Leiden
COD	Chemical Oxygen Demand
EP	Eutrophication Potential
EZH	Energiemaatschappij Zuid-Holland (electricity company)
FAETP	Fresh water Aquatic Eco-Toxicity Potential
GPPS	General Purpose PolyStyrene
GWP	Global Warming Potential
HIPS	High Impact PolyStyrene
HTP	Human Toxicity Potential
ISO	International Standard Organisation
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LHV	Lower Heating Value
LPB	Liquid Packaging Board
MAETP	Marine Aquatic Eco-Toxicity Potential
MSWI	Municipal Solid Waste Incineration Plant
N	No
NVZ	Netherlands Association of Soap Manufacturers
ODP	Ozone Depletion Potential
PC	Pre-Consumer
PE	PolyEthylene
PNEC	Predicted No-Effect Concentration
POCP	Photochemical Ozone Creation Potential
PPF	Paper-Plastic Fraction
PS	PolyStyrene
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)
RWZI	Sewage Purification Plant
SBB	Solid Bleached Board
TETP	Terrestrial Eco-Toxicity Potential
UCTE	Union for the Co-ordination of Transmission of Electricity
VLCA	Construction Life cycle assessment Association
VOC	Volatile Organic Compounds
Y	Yes

10. Responsibility

Principal's name and address:

Stichting Disposables Benelux
Postbus 12
3740 AA Baarn

Names and positions of project staff:

T.N. Ligthart
A.M.M. Ansems

Names of institutions to which part of the investigation was outsourced:

-

Date on which or time frame within which the investigation was made:

July 2005 – July 2007

Signature:	Approved by:
A.M.M. Ansems	R.A.W. Albers
Project Leader	Team Manager

Annex 1 Review Report and Statements from review panel

Date : 31 October 2007

To : Mr. T. Lighart, TNO, The Netherlands
Mr. A. Ansems, TNO, The Netherlands
Benelux Disposables Foundation

From : Review panel consisting of :

Theo Geerken, VITO, Belgium (chairperson)
Päivi. Harju-Eloranta, Stora-Enso, Finland
Kasturirangan Kannah, NOVA Innovene, UK
Yannick. Leguern, BIO Intelligence Service, France

About : Review Report from review panel about the study :

TNO report

2006-A-R0246(E)/B

Single use Cups or Reusable (coffee) Drinking Systems: An Environmental Comparison

Introduction :

TNO has performed a comparative LCA study for Benelux Disposables Foundation for single use and reusable (coffee) drinking systems in an office or factory environment.
As the intention exists to disclose the comparative assertion to the public and the study claims to be ISO compliant a review by interested parties has been performed.

Function of the Review

The review of an LCA shall ensure that:
the methods used to carry out the LCA are consistent with the ISO standards;
the methods used to carry out the LCA are scientifically and technically valid;

the data used are appropriate and reasonable in relation with the scope and goal of the study;
the interpretations reflect the limitations identified and the goal of the study;
the study report is transparent and consistent.

Review process

The review process consisted of the following steps :

1. Presentation of the study results (by the executor), the review procedures (by the chairman) and questions from the review panel to the executors (May 2007).
2. Preparation of individual review statements and a consensus review statement including recommendations (June 2007)
3. Preparation of a response by the executors of the study (July 2007)
4. Preparation of this review report (August 2007)

Final appreciation from review panel

The review panel appreciates the open explanations and answers that the executors of the LCA study have given during the meeting in Brussels on 14 may 2007.

The review panel has noticed that the recommendations mentioned in the consensus review statement (clear separation between ISO compliant part and non-ISO compliant shadow cost part, completion of goal and scope, more evidence for justification of claim for European representativeness, use of ISO standardized terms) have all been accepted by the executors , elaborated in an additional sensitivity analysis, and included in the final report. All other issues on data quality and reporting have also been clarified and dealt with in a satisfactory way.

The review panel wants to draw the attention of the reader to two issues :

- the study is about (coffee) drinking systems in office or factory environment. There do exist heavier “take a way” drinking cups for instance in expanded EPS or paper version but they are not considered in this study.
- The type of cleaning and the frequency of cleaning of the earthenware mug in practice varies a lot and determines the environmental impact of this option to a very large extent.

The review panel considers the study to be compliant both with the set of ISO standards (14040:1997, 14041:1998, 14042:2000, 14043:2000) valid until mid 2006 and the set (14040: 2006, 14044:2006) valid as from mid 2006.

TNO Built Environment and Geosciences

Memorandum

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info@mep.tno.nl

To
Theo Geerken, VITO
Päivi. Harju-Eloranta, Stora-Enso
Kasturirangan Kannah, NOVA Innovene
Yannick. Leguern, BIO Intelligence Service

From
T.N. Ligthart

Date
18 July 2007

Subject
Reaction to review statement

Our reference

In this memo I will respond to the review statement of 22 June 2007.

ISO compliance	The report does not make a clear and consequent separation between the LCA study according to the ISO 14040,14041,14042,14043 Standards and the additional shadow cost assessment. **Recommendation 1**.: make a clear explicit separation in reporting on the ISO compliant LCA part and the shadow cost part. This clear separation is needed also for the management summary. We have made a clear separation between the ISO conform part and non-conform parts. **Recommendation 2** :even in the suggested second part (outside the ISO compliant part) about shadow costs it is recommended to draw conclusions in terms of shadow costs from environmental pollution and not in terms of environmental pollution. Conclusions have been drawn in terms of environmental burden expressed in shadow costs	**major issue**
Goal and scope of the study.	Goal and scope definition is not complete. Important missing elements are : • intended audience • data requirements • limitations • type of critical review **Recommendation 3**: adress these elements in the goal and scope We have updated the goal and scope. The studied systems are to the opinion of the review panel not	**major issue**

Date
18 July 2007

Our reference

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	fully representative for the Western European situation : This comment is made with particular reference to the chosen drinking systems, especially the non inclusion of the EPS cup. When queried on this omission during the review meeting on 14th May, the authors suggested that the EPS cup is not widely used in the Netherlands. While this is true, it is also a fact that the EPS cup is finding increasing favour in the UK and Mediterranean countries The EPS cup is mainly used as an "to-go" cup as an vending cup is much less used. It has therefore been left out. The foaming of the cup instead of inline thermoforming will increase the environmental impact of this type of PS cup • PS cup recycling rate of 50 % seems high (is there a reference probably for Benelux ?) considering the fact that in general in Europe fibre based packaging recovery and recycling rates are 81% and 70% respectively while corresponding rates for plastic packaging are 51% and 25% • Is not recycling rate but allocation factor • What are the distances taken into account for transports? Are they representative of the European situation? • The transport distances have been given. The representativity is assumed to be OK but could not be checked. . • What is the representativeness of the end of life scenario? (% landfill, % MSWI, % recycling…). As it is indicated in the report, we can understand that this end of life scenario is representative of the Dutch situation. If this study has to be representative of the European situation, indication should be given on the differences between the Dutch and European situation (for both cases: % landfill, % MSWI, % recycling…). If these differences are important, the end of life scenario should be modified. **Recommendation 4**: either reduce the claim to Benelux, or give more evidence for justification of the claim. We will add sensitivity analysis with EU-15 end-of-life situation. In the UK and in Switzerland cup recycling schemes are active.	
System boundaries.	No information is given for packaging in all systems studied. This could be an important issue for disposable drinking systems. Even if this item is not taken into account in this study, a qualitative assessment should be given in order to justify that packaging is negligible for disposable drinking systems. For example, the ratio weight of packaging / 100 disposable cups could justify this hypothesis. The transport packaging is estimated at less then 10% at mass base. Beside this the recycling rate is very high reducing the environmental impact even further. This is mentioned in the	**minor issue**

	report. System descriptions on page 19 and 20 : It is not very clear from the diagrams called "system limits" (see also **Recommendation 5**: use ISO standardised term "system boundaries") how the credits of production of secondary raw materials or the credits of production of energy from waste processes are taken into account. The ISO standards provide options for system-expansion to solve this. We will change terms into "ISO terms". Diagrams will be checked.	
Data quality and representativeness.	The representativeness of the data used for the LCA should be more detailed in the final report (technological, geographical, temporal…). For example : The electricity mix and year of reference should be indicated. We have given more complete details on data used. The earthenware mug base case of washing it after each use with 0.4 l hot water liter hot water seems very pessimistic. Also it is not clear how the standby energy is attributed to possibly other uses of the same boiler (washing hands or other uses). A small enquiry in office showed washing frequencies between 1 and 10 mug uses of coffee between washing, with the median somewhere around 4 uses. Quite a lot of people use cold water + a tissue after a number of uses. The amount of water varies between 0.1 and 0.4 l. A frequency of two uses before washing seems more realistic as base case because the earthenware mug is a personal tool. In the small enquiry people showed to drink the first mug in the canteen and sometimes take the second mug immediately afterwards in the canteen or into their own office, without washing intermediary. The chosen base case is definitely a very pessimistic choice. The earthenware mug was given the same cleaning frequency for the ease of comparison with the porcelain cup and saucer. In the conclusions it is already mentioned that user behavior is critical. In the report the following is now mentioned: "The base case was questioned for its representativity in the reviewing process for its high cleaning frequency. The influence on environmental effects of another cleaning frequency or type of cleaning of the earthenware mug already determined in a sensitivity analysis (see section 5.3 and 6.8.2) will therefore get extra attention in the evaluation of the results.".	**major issue** **major issue**

<table>
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The footnote about the Food and Drugs Act regulation needs a lot more clarification with respect to the valid regulation for users in this context. (regulation valid for which country, what are the exact requirements, is it directed towards hot or cold water washing etc.).
Footnote is less prominent and changed to HACCP guidelines. A too low cleaning frequency can indeed be a critical point.
</td>
<td>Major issue</td>
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The sensitivity analysis varying the weight of disposable cups has been performed using a variation of +/- 20 % both for paper and PS cups. This seems a small variation as there are indications that for instance Mc Donalds uses a 7oz/200 ml double wall paper cup and coffee houses such as Costa also have similar weight cups. Could the executors explain on what data the range of +/- 20 % has been based ?
The variation is based on vending cups. “to-go” cups as used at public points of sale may use heavier cups as there are different demands.
</td>
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The mix of GPPS and HIPS (60 / 40) used in cup production should be checked
Data from Disposables Benelux, reference has been given
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<td>Minor issue</td>
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The scores obtained for the comparison of the drinking systems showed that the reusable earthenware mug is the most polluting system for seven of the ten categories (ADP, GWP, HTP, MAETP, TETP, POCP and AP). According to the authors during the joint meeting (14 may 2007), life cycle inventory used for the production of polystyrene cups is coming from PlasticsEurope’s Ecoprofils and life cycle inventories used for electricity production and earthenware mug production are taken from Ecoinvent database. One aspect when using different kinds of database in LCA is that there is not always the same elementary flows taken into account. For example,
<table>
<tr><td></td><td>Compartment</td><td>PlasticsEurope LCI</td><td>Ecoinvent</td></tr>
<tr><td>Chromium</td><td rowspan="2">Air</td><td>Cr+compounds</td><td>Cr and Cr VI</td></tr>
<tr><td>Particulates</td><td>Dust (PM10)</td><td>Particulates, < 2.5 um, Particulates, > 10 um and Particulates, > 2.5 um, and < 10um</td></tr>
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<td>Minor issue</td>
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Date
18 July 2007

Our reference

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	Furthermore, Ecoinvent does not present "clusters" whereas PlasticsEurope present some ("metals not specified" in PlasticsEurope). We have used the most complete LCI data, namely Ecoinvent. Actually the ecoinvent data are based on Plastics Europe data. These flows can have a significant influence on toxicological and ecotoxicological indicators. As these categories are of major importance on the results with the shadow prices approach, information should be given on the sensitivity of the results linked to the fact that there are not the same flows in the two databases. For example, a sensibility analysis could be done with the same elementary flows for all drinking systems.	
	For PS cups more end-of-life scenario's have been considered compared to the paper cup. Shouldn't this also be done for the paper cup : regarding sub-coal option and material recycling ? Sub-coal will be added for the paper cup as a sensitivity analysis.	**Major issue**
	There are some questions about the chosen energy data for the paper cups that need clarification: - External energy for board production according to Ecoinvent LPB data is 80% Nordel and 20% UCTE, is that used in calculations? - YES - Is external energy used for cup processing 100% UCTE? - YES - What is the energy use for cup production (PE coating and cup converting)? Reference is made to Ecoinvent LPB converting data, which includes PE and aluminium coating and converting. Is this LPB coating data multiplied with 1,5 for cup production or what does 150% mean in table 6? 1,5 * energy need for LPB converting = 1,5* 400 kWh/t = 600 kWh/t? - Energy use based on Benders + LPB. Average is 150% of energy use of LPB. reference wil be made in report. - Annex 2, page 1/6: is used electricity mix based on Netherland's grid electricity or UCTE? Is UCTE, table will be updated	**Minor issue**
	- Generic data has been used for raw materials used in all compared systems. Data quality for converting of single use cups is less comparable. Specific data is used for thermoforming of PS cups while paper cup production is roughly estimated with other type of packaging. Is best available case - LPB data is used instead of SBB even though SBB is the board grade actually used for paper cups. SBB data in Ecoinvent has some mistakes and therefore the use of LPB is appropriate. OK	**Minor issue**

Date
18 July 2007

Our reference

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	Remarks on generic Ecoinvent data for LPB, please a reaction from the executors of the study: - In Ecoinvent database wood basic densities are too high for Scandinavian wood. Basic densities of wood in Ecoinvent are based on beech and spruce data in Europe. Scandinavian fibrewood species are birch, pine and spruce which have lower basic densities than used in Ecoinvent. This is significant for European average data sets because about 60% of European pulp is produced in Scandinavia and the share is even higher for chemical pulps. - We did not have these details available. Will lead to higher use of volume of wood not of mass. Impact is assumed to be not significant. - LPB in Europe is produced in Finland and Sweden from Scandinavian wood (LPB produced in Russia is used in Russia), which means that wood consumption and following land use data is biased in Ecoinvent database - As I can see LPB is Scandinavia based. - External energy for LPB production is assumed to be 80% Nordel and 20% UCTE, which is not quite correct due to the fact that 100% of European LPB production takes place in Scandinavia. - Scandinavia 20% imports form UCTE!! There are no HDPE coated paper cups available on the market, they are all LDPE coated. The report should explain the reasons why nonetheless HDPE coated cups have been chosen. HDPE was used to be on the safe side, has a insignificant higher impact than LDPE. Report now mentions PE.	**Minor issue** **Minor issue**
Reporting	On many pages expressions are used that have a standardized ISO equivalent or definition (**Recommendation 5 :** use ISO standardized terms where possible): OK p. 16 Life cycle analysis -→ life cycle assessment p 17; Objective and scope -→ goal and scope p 35 starts with the ISO 14043 definitions about the wordings to be used for different contributions (> 50 %, until <2.5 %) but in the pages that follow all kind of different wordings are introduced like : p.35 “minor” p. 37 “highly” p. 38 “most decisive” p 38 “most contributory” p.40 “little if any” p. 42 “very important to most important” p. 53 “ little” p. 38 “standardized environmental profile” → normalized	**major issue**

Date
18 July 2007

Our reference

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	environmental profile (also on p 41 and probably more) Have been made in line description The functional unit has been chosen as the dispensing of 1000 units of hot drinks from a vending machine or dispenser. It is not clear whether this relates to 150 ml / 180 ml, as mentioned on page 18 of the report or 180 ml / 200 ml, as noted on the slides presented at the 14th May meeting. What volume is correct ? Paper 180/200 PS 150/180 as on market. - No reference to applied normalisation method is made. Is the normalisation valid for Netherlands only or also for other Western Europe? - Western Europe - Table 31, Source should be 31 and 32 instead of 25 and 26. English reference for shadow price method should be included. - OK - Page 93, sentence ”Disposable systems continue...” is not entirely in line with Figure 42. - CHECKed & updated	

The editorial comments/ smaller comments have all been implemented.

Date : 22 June 2007

To : Mr. T. Lighart, TNO, The Netherlands
Mr. A. Ansems, TNO, The Netherlands

From : Review panel consisting of :

Theo Geerken, VITO, Belgium (chairperson)
Päivi. Harju-Eloranta, Stora-Enso, Finland
Kasturirangan Kannah, NOVA Innovene, UK
Yannick. Leguern, BIO Intelligence Service, France

About : Review statement from review panel about the study :

TNO report

2006-A-R0246(E)/B

Single use Cups or Reusable (coffee) Drinking Systems: An Environmental Comparison

Introduction :
The review panel appreciates the open explanations and answers that the executors of the LCA study have given during the meeting in Brussels on 14 May 2007.
Below we have summarized both the main and detailed findings in a review statement.
Based on the responses of the executors a review report will be produced.

ISO compliance	The report does not make a clear and consequent separation between the LCA study according to the ISO 14040,14041,14042,14043 Standards and the additional shadow cost assessment. Although the applied shadow cost method provides interesting additional policy relevant information for the Netherlands it can not be considered fully representative for the Western-European situation, due to different environmental policy objectives among countries. The sentence " A comparison of the beverage systems investigated shows that the reusable mug is the most environmentally polluting system at 4.67 Euro" (on p.7 and more pages) is in direct conflict with the ISO Standards (definition of comparative assertion, and requirement that a sufficiently comprehensive set of category indicators should be employed to support comparative assertions). **Recommendation 1**.: make a clear explicit separation in reporting on the ISO compliant LCA part and the shadow cost part. This clear separation is needed also for the management summary. **Recommendation 2** :even in the suggested second part (outside the ISO compliant part) about shadow costs it is recommended to draw conclusions in terms of shadow costs from environmental pollution and not in terms of environmental pollution.	**major issue**
Goal and scope of the study.	Goal and scope definition is not complete. Important missing elements are : • intended audience • data requirements • limitations • type of critical review **Recommendation 3**: address these elements in the goal and scope The studied systems are to the opinion of the review panel not fully representative for the Western European situation : This comment is made with particular reference to the chosen drinking systems, especially the non inclusion of the EPS cup. When queried on this omission during the review meeting on 14th May, the authors suggested that the EPS cup is not widely used in the Netherlands. While this is true, it is also a fact that	**major issue**

<table>
<tr><td></td><td>the EPS cup is finding increasing favour in the UK and Mediterranean countries
• PS cup recycling rate of 50 % seems high (is there a reference probably for Benelux ?) considering the fact that in general in Europe fibre based packaging recovery and recycling rates are 81% and 70% respectively while corresponding rates for plastic packaging are 51% and 25%
• What are the distances taken into account for transports? Are they representative of the European situation?

• What is the representativeness of the end of life scenario? (% landfill, % MSWI, % recycling…).
As it is indicated in the report, we can understand that this end of life scenario is representative of the Dutch situation. If this study has to be representative of the European situation, indication should be given on the differences between the Dutch and European situation (for both cases: % landfill, % MSWI, % recycling…). If these differences are important, the end of life scenario should be modified.

Recommendation 4: either reduce the claim to Benelux, or give more evidence for justification of the claim.</td><td></td></tr>
<tr><td>System boundaries.</td><td>No information is given for packaging in all systems studied. This could be an important issue for disposable drinking systems. Even if this item is not taken into account in this study, a qualitative assessment should be given in order to justify that packaging is negligible for disposable drinking systems. For example, the ratio weight of packaging / 100 disposable cups could justify this hypothesis.

System descriptions on page 19 and 20 : It is not very clear from the diagrams called “system limits” (see also Recommendation 5: use ISO standardised term “system boundaries”) how the credits of production of secondary raw materials or the credits of production of energy from waste processes are taken into account. The ISO standards provide options for system-expansion to solve this.</td><td>minor issue</td></tr>
<tr><td>Data quality and representativeness.</td><td>The representativeness of the data used for the LCA should be more detailed in the final report (technological, geographical, temporal…).
For example : The electricity mix and year of reference should be indicated.</td><td>major issue</td></tr>
</table>

	The earthenware mug base case of washing it after each use with 0.4 l hot water liter hot water seems very pessimistic. Also it is not clear how the standby energy is attributed to possibly other uses of the same boiler (washing hands or other uses). A small enquiry in office showed washing frequencies between 1 and 10 mug uses of coffee between washing, with the median somewhere around 4 uses. Quite a lot of people use cold water + a tissue after a number of uses. The amount of water varies between 0.1 and 0.4 l. A frequency of two uses before washing seems more realistic as base case because the earthenware mug is a personal tool. In the small enquiry people showed to drink the first mug in the canteen and sometimes take the second mug immediately afterwards in the canteen or into their own office, without washing intermediary. The chosen base case is definitely a very pessimistic choice.	**major issue**
	The footnote about the Food and Drugs Act regulation needs a lot more clarification with respect to the valid regulation for users in this context. (regulation valid for which country, what are the exact requirements, is it directed towards hot or cold water washing etc.).	**Major issue**
	The sensitivity analysis varying the weight of disposable cups has been performed using a variation of +/- 20 % both for paper and PS cups. This seems a small variation as there are indications that for instance Mc Donalds uses a 7oz/200 ml double wall paper cup and coffee houses such as Costa also have similar weight cups. Could the executors explain on what data the range of +/- 20 % has been based ?	**Minor issue**
	The mix of GPPS and HIPS (60 / 40) used in cup production should be checked	**Minor issue**
	The scores obtained for the comparison of the drinking systems showed that the reusable earthenware mug is the most polluting system for seven of the ten categories (ADP, GWP, HTP, MAETP, TETP, POCP and AP). According to the authors during the joint meeting (14 may 2007), life cycle inventory used for the production of polystyrene cups is coming from PlasticsEurope's Ecoprofils and life cycle inventories used for electricity production and earthenware	**Minor issue**

mug production are taken from Ecoinvent database. One aspect when using different kinds of database in LCA is that there is not always the same elementary flows taken into account. For example,

	Compartment	PlasticsEurope LCI	Ecoinvent
Chromium	Air	Cr+compounds	Cr and Cr VI
Particulates		Dust (PM10)	Particulates, < 2.5 um , Particulates, > 10 um and Particulates, > 2.5 um, and < 10um

Furthermore, Ecoinvent does not present “clusters” whereas PlasticsEurope present some (“metals not specified” in PlasticsEurope).

These flows can have a significant influence on toxicological and ecotoxicological indicators. As these categories are of major importance on the results with the shadow prices approach, information should be given on the sensitivity of the results linked to the fact that there are not the same flows in the two databases. For example, a sensibility analysis could be done with the same elementary flows for all drinking systems.

For PS cups more end-of-life scenario’s have been considered compared to the paper cup. Shouldn’t this also be done for the paper cup : regarding sub-coal option and material recycling ?

Major issue

There are some questions about the chosen energy data for the paper cups that need clarification:

- External energy for board production according to Ecoinvent LPB data is 80% Nordel and 20% UCTE, is that used in calculations?
- Is external energy used for cup processing 100% UCTE?
- What is the energy use for cup production (PE coating and cup converting)? Reference is made to Ecoinvent LPB converting data, which includes PE and aluminium coating and converting. Is this LPB coating data multiplied with 1,5 for cup production or what does 150% mean in table 6?

Minor issue

	1,5 * energy need for LPB converting = 1,5* 400 kWh/t = 600 kWh/t? - Annex 2, page 1/6: is used electricity mix based on Netherland's grid electricity or UCTE? - Generic data has been used for raw materials used in all compared systems. Data quality for converting of single use cups is less comparable. Specific data is used for thermoforming of PS cups while paper cup production is roughly estimated with other type of packaging. - LPB data is used instead of SBB even though SBB is the board grade actually used for paper cups. SBB data in Ecoinvent has some mistakes and therefore the use of LPB is appropriate.	 **Minor issue**
	Remarks on generic Ecoinvent data for LPB, please a reaction from the executors of the study: - In Ecoinvent database wood basic densities are too high for Scandinavian wood. Basic densities of wood in Ecoinvent are based on beech and spruce data in Europe. Scandinavian fibrewood species are birch, pine and spruce which have lower basic densities than used in Ecoinvent. This is significant for European average data sets because about 60% of European pulp is produced in Scandinavia and the share is even higher for chemical pulps. - LPB in Europe is produced in Finland and Sweden from Scandinavian wood (LPB produced in Russia is used in Russia), which means that wood consumption and following land use data is biased in Ecoinvent database - External energy for LPB production is assumed to be 80% Nordel and 20% UCTE, which is not quite correct due to the fact that 100% of European LPB production takes place in Scandinavia.	**Minor issue**
	There are no HDPE coated paper cups available on the market, they are all LDPE coated. The report should explain the reasons why nonetheless HDPE coated cups have been chosen.	**Minor issue**
Reporting	On many pages expressions are used that have a standardized ISO equivalent or definition (**Recommendation 5 :** use ISO standardized terms where possible): p. 16 Life cycle analysis -→ life cycle assessment p 17; Objective and scope -→ goal and scope	**major issue**

	p 35 starts with the ISO 14043 definitions about the wordings to be used for different contributions (> 50 %, until <2.5 %) but in the pages that follow all kind of different wordings are introduced like : p.35 "minor" p. 37 "highly" p. 38 "most decisive" p 38 "most contributory" p.40 "little if any" p. 42 "very important to most important" p. 53 " little" p. 38 "standardized environmental profile" → normalized environmental profile (also on p 41 and probably more) The functional unit has been chosen as the dispensing of 1000 units of hot drinks from a vending machine or dispenser. It is not clear whether this relates to 150 ml / 180 ml, as mentioned on page 18 of the report or 180 ml / 200 ml, as noted on the slides presented at the 14th May meeting. What volume is correct ? - No reference to applied normalisation method is made. Is the normalisation valid for Netherlands only or also for other Western Europe? - Table 31, Source should be 31 and 32 instead of 25 and 26. English reference for shadow price method should be included. - Page 93, sentence "Disposable systems continue..." is not entirely in line with Figure 42.	

Below a list is given of smaller but still relevant suggestions for improving the correct understanding and readability of the study and it's results :

- Date of report is mentioned as December 2006 (cover page), whereas time frame for investigation is noted as July 2005 – June 2007 (Section 10)
- Abbreviations page to be checked and English abbreviations used wherever appropriate; expanded terms to be corrected in a few areas, eg, Chemical Oxygen Demand for COD; terms such as BOD are missing and are to be included.

  p. 5: Last paragraph "No conclusions" -→ No final conclusions
  p 9, second sentence from the bottom has the word "driningen" cup

p. 11 : shadow cost method should conclude about shadow costs and not “environmental pollution”.
p. 26 : the second paragraph shows the many options and differences in data inventory , it is not fully transparant what has been chosen within this study and how it relates to the others.
p. 37 “for the dishwasher “-→ for the use of the dishwasher
p. 38 eutropy → eutrophication (also on p. 63 etc.)
p. 44 “as already stated” : where was this stated ?
p 44 “ then the highest” → “the second highest “
p 51. “conclusions”-→ “final conclusions”
p 57 “substance of the environmental profile” : what do you mean ?
p. 62 “change from “equivalent” to poorer” performing : what systems are compared and how ?
p. 63 “highest scoring system” with the graph above could be misinterpreted: the mug gets the lowest contribution to the categories.
p. 66 “effects become significantly less quickly” : what does that mean ?
p. 67 just under the table, do not understand the word “consequently “ First one can see how effect categories are changed then one can conclude and not the otherway around.

- Annex 1, a few suggestions: “Man made” to be included before the definition of climate change. CFC 11 instead of CFH 11. Page 3 of this Annex suggests C2H2 as a reference for smog formation, this should be checked.

Annex 2 Environmental effect categories

Abiotic mineral resources Depletion Potential (ADP)
Abiotic raw materials are natural resources regarded as lifeless, such as iron ore and crude oil. The exhaustion of abiotic mineral resources is one of the most discussed effect categories and a great variety of different methods is therefore available to characterise the contributions to this category. The exhaustion of scarce raw materials is assessed against the total stock of the material (metal, mineral, energy carrier) present in the earth's crust by comparison with annual consumption. The exhaustion of antimony (Sb) is used as a reference.

Global Warming Potential (GWP)
Climate change, called the “greenhouse effect” in popular parlance, is defined as the effect of man-made emissions on the heat radiation absorbent capacity of the atmosphere. The average temperature in the atmosphere increases in consequence, possible effects of which are an increase in sea levels and changes in the water system, such as a change in the average rain precipitation and extreme rain precipitation. This can in turn have negative effects on the stability of eco-systems, public health and material prosperity. Greenhouse gases each have a different Global Warming Potential (GWP) and each individual emission can be converted into an equivalent quantity of carbon dioxide (CO_2) emission.

A minor change has been made in the method with regard to the GWP effect category. The absorption of CO_2 from the air by trees (used for the production of paper and carton) and the emission of short-cycle CO_2 released on combustion of carton and paper has no effect on GWP. This takes account of the fact that these materials are CO_2-neutral.

Ozone Depletion Potential (ODP)
Depletion on the stratospheric ozone layer through human emissions ensures that a greater proportion of UV-B radiation from the sun reaches the earth's surface. This has potentially harmful effects on public health, terrestrial and aquatic ecosystems, biochemical cycles, and substances. The most important ozone layer depletion substances are the so-called chloro-fluoro-hydrocarbons (CFCs) and halons. The ozone layer depletion capacity of these substances is expressed in equivalents of the reference substance CFC-11.

Human Toxicity Potential (HTP)
Fresh water Aquatic Eco-Toxicity Potential (FAETP)
Marine Aquatic Eco-Toxicity Potential (MAETP)
Terrestrial Eco-Toxicity Potential (TETP)
To determine potential toxicity of a substance, a multimedia distribution model is used, USES 2.0, developed by RIVM and translated into LCA application by the University of Amsterdam [8]. Using substance-specific distribution factors, how

much of an initial emission eventually *potentially* reaches other environmental compartments is determined. The quantities calculated per substance are then divided per environmental compartment by a factor derived from toxicology, such as acceptable daily intake (ADI) or predicted no-effect concentration (PNEC), depending on the effect category and the substances group.

Human toxicity refers to the effects of toxic substances in the environment on public health. Freshwater aquatic ecotoxicity and marine aquatic ecotoxicity refer to the effect of toxic substances on freshwater aquatic ecosystems and marine aquatic ecosystems respectively. Terrestrial ecotoxicity refers to the effects of toxic substances on terrestrial ecosystems. Human toxicity, (fresh water and marine) aquatic ecotoxicity and terrestrial ecotoxicity are all expressed in 1.4-dichlorobenzene equivalents.

Apeldoorn Declaration
Ecotoxicity of metals, in particular, has been found not to be satisfactorily modelled by the CML2 method. Especially high and unrealistic scores often occurred for freshwater and marine ecotoxicity. A group of LCA, risk assessment and ecotoxicity specialists consequently drew up the so-called "Apeldoorn Declaration" in 2004 [10]. This declaration indicates why the said high scores for metals are incorrect, why aspects such as bio-availability, essentiality and speciation are not included in the determination and how these inadequacies must be dealt with. The declaration makes the following recommendations:
1. The fact that a number of critical points concerning metals is insufficiently included in the present characterisation models for ecotoxicity must be clearly communicated as a component of an LCIA report. Policy decisions or business decisions should consequently not be taken without further discussion on the basis of the present, and incomplete, methods for assessing ecotoxicity in LCIA.
2. Account should already be taken from the inventory stage of chemical speciation of metals; emissions should be reported in terms of metal species, preferably in terms of dissolved metal quantity instead of total metal quantity.
3. If the contribution analysis of the LCIA shows that metals have a dominant influence on the results (and conclusions), a sensitivity analysis would have to be carried out with a time horizon of 100 years. This concerns the toxicity effects, if applicable, or the exclusion of metals within the toxicity effects.
4. The oceans are deficient in essential metals. Further additions of essential metals would therefore probably not result in toxic effects. The characterisation factors for ecotoxicity of essential metals should therefore be set at zero. This need not be the case with coastal waters.

Photochemical Ozone Creation Potential (POCP)
Photochemical ozone creation is the formation of reactive chemical compounds, such as ozone, through the effects of sunlight on certain primary air-polluting substances. These reactive compounds may be harmful both to health and to crops. Photochemical oxidants may be formed under the influence of ultraviolet light in

the troposphere through the photochemical oxidation of volatile organic compounds (VOC) and carbon monoxide (CO) in the presence of nitrogen oxides (NO_x). The capacity for substances to form smog is determined with C_2H_2 as reference.

Acidification potential (AP)

Acidification substances have a long series of effects on the soil, ground water, surface waters, organisms and ecosystems. Acidification is caused by emissions of Acidification substances to the air; the chief acidating emissions are SO_2, NO_x and NH_x. The acidification capacity of an emission is converted to SO_2-equivalents. Examples of the consequences of acidification include amongst other things the reduction in forests, the deterioration of building materials and the death of fish in ScandinMSWIan lakes.

Eutrophication potential (EP)

Eutrophication covers all potential effects of excessively high levels of macro-nutrients; the most important of these are nitrogen (N) and phosphorous (P). Nutrient enrichment can change the composition of species in undesirable ways and increase biomass production in both aquatic and terrestrial ecosystems. High concentrations of nutrients can, moreover, make surface water unsuitable as drinking water. In aquatic ecosystems, the enhanced biomass can result in reduced oxygen levels on account of additional oxygen consumption through biomass decomposition. The total fertilising effect of an emission is converted to PO_4-equivalents.

Annex 3 Life Cycle Inventory data

This annex includes the LCI data for the use of a dishwasher (reusable systems) and the use of the sewage purification plant (RWZI). The latter is based on Ecoinvent's "wastewater treatment plant 2" [15].

Products	**Amount**	**Unit**	**Comment**
Dishwasher (unit)	**1**	**p**	**100%**
Resources			
Materials/fuels			
Tap water, at user/CH S	0.126	kg	
Detergent (kg)	0.4	g	
Electricity/heat			
Electricity Low Voltage use in UCTE	0.0124	kWh	washing per unit
Electricity Low Voltage use in UCTE	0.006	kWh	drying per unit
Waste water treatment (m3)	0.000126	p	0.126 l water
Emissions to air			
Emissions to water			
Emissions to soil			
Final waste flows			
Waste to treatment			

Products	Amount	Unit	Comment
Dishwasher TAUW (kg)	**1**	**p**	**100%**
Resources			
Materials/fuels			
Tap water, at user/CH S	0.68	kg	
Detergent (kg)	0.91	g	per kg of porcelain
Electricity/heat			
Electricity Low Voltage use in UCTE	0.545	MJ	
Waste water treatment (m3)	0.00068	p	0.68 l
Emissions to air			
Emissions to water			
Emissions to soil			
Final waste flows			
Waste to treatment			

Products	Sub-compartment	Unit	Amount
RWZI (m3)		**p**	**1**
Resources			
Materials/fuels			
Slurry spreading, by vacuum tanker/CH U		m^3	0.000327
Aluminium sulphate, powder, at plant/RER U		kg	0.00315
Ammonia, liquid, at regional storehouse/CH U		kg	7.21E-05
Chemicals inorganic, at plant/GLO U		kg	6.58E-07
Chromium oxide, flakes, at plant/RER U		kg	4.21E-08
Hydrochloric acid, 30% in H_2O, at plant/RER U		kg	3.95E-07
Iron (III) chloride, 40% in H_2O, at plant/CH U		kg	0.0159
Sodium hydroxide, 50% in H_2O, production mix, at plant/RER U		kg	0.000352
Titanium dioxide, production mix, at plant/RER U		kg	2.06E-06
Chemicals organic, at plant/GLO U		kg	5.25E-07
Quicklime, milled, packed, at plant/CH U		kg	1.25E-06
Cement, unspecified, at plant/CH U		kg	0.00148
Electricity, low voltage, at grid/CH U		kWh	0.193
Iron sulphate, at plant/RER U		kg	0.0117
Natural gas, burned in industrial furnace low-NOx		MJ	0.00703

Products	Sub-compartment	Unit	Amount
RWZI (m3)		**p**	**1**
>100kW/RER U			
Transport, lorry 28t/CH U		tkm	0.0118
Transport, freight, rail/RER U		tkm	0.0195
Electricity/heat			
Electricity from waste, at municipal waste incineration plant/CH U		kWh	0.0186
Heat from waste, at municipal waste incineration plant/CH U		MJ	0.109
Municipal waste incineration plant/CH/		p	3.24E-11
Slag compartment/CH/I U		p	4.20E-11
Residual material landfill facility/CH/		p	7.71E-12
Sewer grid, class 2/CH/I U		km	1.68E-07
Wastewater treatment plant, class 2/CH/		p	0.00E+00
Emissions to air			
Aluminium	high. pop.	kg	1.41E-06
Ammonia	high. pop.	kg	0.000356
Arsenic	high. pop.	kg	2.53E-10
Cadmium	high. pop.	kg	4.73E-12
Calcium	high. pop.	kg	5.10E-06
Carbon dioxide, biogenic	high. pop.	kg	0.184
Carbon monoxide, biogenic	high. pop.	kg	0.000171
Chromium	high. pop.	kg	2.73E-13
Cobalt	high. pop.	kg	1.55E-14
Copper	high. pop.	kg	1.26E-10
Cyanide	high. pop.	kg	1.29E-06
Dinitrogen monoxide	high. pop.	kg	0.000152
Heat, waste	high. pop.	MJ	1.25
Iron	high. pop.	kg	2.72E-07
Lead	high. pop.	kg	1.75E-10
Magnesium	high. pop.	kg	4.73E-07
Manganese	high. pop.	kg	8.72E-14
Mercury	high. pop.	kg	3.37E-13
Methane, biogenic	high. pop.	kg	0.000502
Molybdenum	high. pop.	kg	5.78E-10
Nickel	high. pop.	kg	6.86E-14
Nitrogen oxides	high. pop.	kg	0.0007
NMVOC, non-methane volatile organic compounds, unspecified origin	high. pop.	kg	2.28E-06
Phosphorus	high. pop.	kg	1.33E-06
Silicon	high. pop.	kg	4.20E-06
Sulphur dioxide	high. pop.	kg	0.000886

Products	Sub-compartment	Unit	Amount
RWZI (m3)		**p**	**1**
Tin	high. pop.	kg	1.61E-09
Zinc	high. pop.	kg	7.57E-10
Emissions to water			
Aluminium	groundwater, l.t.	kg	0.000669
Aluminium	river	kg	6.23E-05
Ammonium, ion	river	kg	0.011
Arsenic, ion	groundwater, l.t.	kg	6.54E-08
Arsenic, ion	river	kg	7.59E-07
BOD5, Biological Oxygen Demand	groundwater, l.t.	kg	8.56E-05
BOD5, Biological Oxygen Demand	river	kg	0.00982
Cadmium, ion	groundwater, l.t.	kg	8.50E-10
Cadmium, ion	river	kg	1.42E-07
Calcium, ion	groundwater, l.t.	kg	0.00266
Calcium, ion	river	kg	0.0459
Chloride	river	kg	0.0405
Chromium VI	groundwater, l.t.	kg	3.91E-07
Chromium VI	river	kg	6.33E-06
Chromium, ion	river	kg	1.18E-08
Cobalt	groundwater, l.t.	kg	4.28E-07
Cobalt	river	kg	8.21E-07
COD, Chemical Oxygen Demand	groundwater, l.t.	kg	0.000262
COD, Chemical Oxygen Demand	river	kg	0.0302
Copper, ion	groundwater, l.t.	kg	1.37E-05
Copper, ion	river	kg	9.71E-06
DOC, Dissolved Organic Carbon	groundwater, l.t.	kg	0.000104
DOC, Dissolved Organic Carbon	river	kg	0.00754
Fluoride	river	kg	3.28E-05
Heat, waste	river	MJ	1.1
Iron, ion	groundwater, l.t.	kg	0.00381
Iron, ion	river	kg	0.0036
Lead	groundwater, l.t.	kg	3.36E-07
Lead	river	kg	9.49E-07
Magnesium	groundwater, l.t.	kg	0.000317
Magnesium	river	kg	0.00515
Manganese	groundwater, l.t.	kg	1.38E-05
Manganese	river	kg	2.69E-05
Mercury	groundwater, l.t.	kg	4.41E-09
Mercury	river	kg	6.27E-08
Molybdenum	groundwater, l.t.	kg	2.39E-07
Molybdenum	river	kg	5.35E-07
Nickel, ion	groundwater, l.t.	kg	1.49E-06

Products	Sub-compartment	Unit	Amount
RWZI (m3)		**p**	**1**
Nickel, ion	river	kg	4.00E-06
Nitrate	groundwater, l.t.	kg	5.13E-05
Nitrate	river	kg	0.0483
Nitrite	river	kg	0.000644
Nitrogen	river	kg	0.00049
Phosphate	groundwater	kg	1.47E-05
Phosphate	groundwater, l.t.	kg	0.000156
Phosphate	river	kg	0.0027
Potassium, ion	river	kg	0.000399
Silicon	groundwater, l.t.	kg	0.000156
Silicon	river	kg	0.000188
Sodium, ion	river	kg	0.00219
Sulphate	groundwater, l.t.	kg	0.00237
Sulphate	river	kg	0.145
Tin, ion	groundwater, l.t.	kg	6.10E-07
Tin, ion	river	kg	1.42E-06
TOC, Total Organic Carbon	groundwater, l.t.	kg	0.000104
TOC, Total Organic Carbon	river	kg	0.0073
Zinc, ion	groundwater, l.t.	kg	7.18E-07
Zinc, ion	river	kg	3.38E-05
Emissions to soil			
Aluminium	agricultural	kg	0.00057
Arsenic	agricultural	kg	7.51E-08
Cadmium	agricultural	kg	5.35E-08
Calcium	agricultural	kg	0.00193
Carbon	agricultural	kg	0.00669
Chromium	agricultural	kg	2.33E-06
Cobalt	agricultural	kg	3.08E-07
Copper	agricultural	kg	1.07E-05
Iron	agricultural	kg	0.00513
Lead	agricultural	kg	2.97E-06
Magnesium	agricultural	kg	0.000217
Manganese	agricultural	kg	1.01E-05
Mercury	agricultural	kg	5.35E-08
Molybdenum	agricultural	kg	1.82E-07
Nickel	agricultural	kg	1.00E-06
Silicon	agricultural	kg	0.00114
Sulphur	agricultural	kg	0.000595
Tin	agricultural	kg	7.65E-07
Zinc	agricultural	kg	2.92E-05

Products	Sub-compartment	Unit	Amount
RWZI (m3)		**p**	**1**
Final waste flows			
Waste to treatment			
Waste	Waste, unspecified	kg	0.0155
Waste	Waste, unspecified	kg	0.0155
Waste	Waste, unspecified	kg	0.13
Waste	Waste, unspecified	kg	0.0236
Waste	Waste, unspecified	kg	0.0037
Waste	Waste, unspecified	kg	0.0037

Annex 4 Shadow Prices

This annex contains Chapter 2 of the TNO Report 'Toxicity has its price'[11].

Methodological background

Environmental costs are external costs
Economic activities are almost without exception accompanied by a certain stress on human being or the environment. For human being , this means an encroachment on health and safety, for the environment, the dislocation of ecosystems, often quantified by a reduction in stocks of clean air, water, soil and biotic and abiotic material [2]. The cost of stress on the environment and human being are not discounted in the product price through the market. That is why they are called external charges, compared with internal production costs.

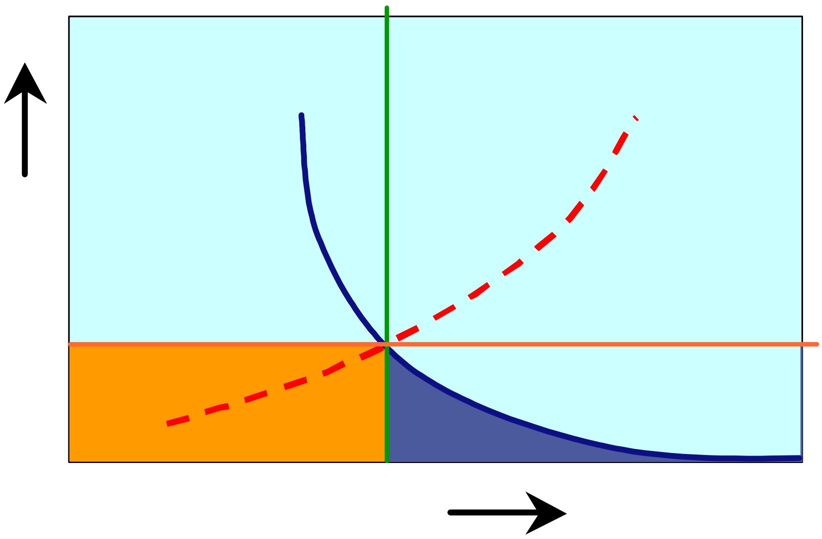

Figure A4.1 Demand for limitation and supply of emission prevention on the virtual environmental market form an equilibrium price. If a government objective crosses the equilibrium point of demand and supply, the shadow price will under this objective be the same as the equilibrium price.

The cost of the environmental burden depends on the price that society is willing to pay for a clean environment and is related to the situation and moment. Generally speaking, the heMSWIer the environmental burden, the greater the willingness to

[11] Harmelen, A.K. van, Ligthart, T.N., Leeuwen, S.M.H. van, Korenromp, R.H.J., Gijlswijk, R.N. van, 2004, Toxicity has its price. Shadow prices for eco and other toxicity and exhaustion of abiotic raw materials within DuboCalc. Commissioned by the Ministry of Transport, Public Works and Water Management, Building Department, Directorate-General for Water affairs.

pay a higher price to limit environmental damage. In this way, a demand curve is created towards limiting environmental damage (see Figure A4.1).

A virtual environmental market
In addition to demand for emission restriction, there is a supply of emission prevention opportunities which also has a particular price for each level of prevention. Generally speaking, the price increases the greater the reduction demanded. If there were to be a market for the environment, demand and supply would form an equilibrium price at the intersection of the curves of marginal damage limitation and marginal prevention cost.

Government restrictions on external effects provide a shadow price
Because external charges are not remunerated through the market, an authority will have to determine to what extent the damage must be limited. This can be done by formulating an emission objective. The point where this objective intersects the marginal damage curve is called the shadow price. This is the extent to which the total cost and benefit change as a result of a change in a limiting factor, in this case the emission limitation. In the present environmental example, the shadow price is in fact the highest permissible environmental cost level per unit of environmental damage that the government is still prepared to bear.

A cost-effective shadow price approximates the equilibrium price
A government that wishes to work cost-effectively positions its emission objective in such a way that it appears at the intersection so that demand and supply are in equilibrium. These total charges concern the cost of the preventive measures in question (the surface beneath the marginal prevention curve to the right of the emission objective) plus the environmental damage sustained as a result of unprevented emissions, the surface beneath the shadow price to the left of the objective. If the government discharges its task as a representative of society properly and works cost-effectively, it will ensure that the shadow price of its environmental objective coincides with the equilibrium price adopted in society. If this is in fact not the case, the perceived environmental damage will increase more strongly in relation to the market equilibrium than the prevention costs will reduce (if the reduction objective is positioned too low) or the prevention expenses will increase more sharply than the environmental damage avoided (if the reduction objective is excessive).

Charging through the shadow price creates an environmental market
However, because the damage is collective, benefits in the form of damage avoided often do not directly profit the investor in prevention costs. In fact, the equilibrium price is virtual. If, on the other hand, the external charges resulting from environmental damage are charged through to the polluter, investment in prevention will certainly result in benefits for the polluter. The damage can, for example, be internalised in the product price. This substantiates an essential criterion of present environmental policy, the “polluter pays principle. This implies

that every individual and every organisation is in principle responsible for the damage caused by him or her to the environment. Moreover, this is done in this manner in an economically cost-effective way. A price has thereby been set for the environment that plays a role in economic dealings. A polluter can decide for himself whether it is advantageous to pay the levy or to reduce his emissions himself and thereby incur additional cost for the reduction measures to be adopted. In either case, the environmentally polluting products will become more expensive and the environmentally friendly less so. This approach with the aid of market-conforming instruments has been the centre of attention in recent years. NO_x equalisation in heavy industry and the negotiable CO_2 emission rights are well-known examples of this.

Application of the shadow price

In addition to the actual charging through of the shadow price by means of e.g. an environmental levy, the shadow price, like the market price, is an easily interpreted signal of economic scarcity. In studies with such varying subjects as life cycle assessment, technological development, sustainability strategies or environmentally friendly designs, in which environmental effects of different kinds must be compared with each other, the shadow price can be easily used to calculate the environmental damage. This is done by multiplying the emissions by the shadow price. The environmental damage calculated in this way, also known as environmental cost or shadow cost, provides an indication of the environmental losses pertaining to present or future emission objectives [5][6][7][8] and [10]. Some studies use the environmental burden calculated in this way in micro-economic cost-benefit analyses, while others do so in micro-economic studies to correct GNP in order thereby to calculate a green GNP [5].

Advantages of the shadow price method

The shadow price has a neutral unit with which various environmental effects can be gathered under a single denominator. Using the shadow price method, different environmental effect categories can be easily weighed up. The shadow price also has the advantage that it dovetails with the use of market-conforming instruments. It also matches the present economic reality in the business world since external charges are rendered visible. It supports integral analyses in order to provide transparent results wherein policy and business can recognise their own activities and the relationship with environmental topics.

Conditions for applying the shadow price method

The shadow price approach is especially suitable for calculating through the present policy or present collective preferences and not for long-term sustainable solutions, because the shadow price of these long-term objectives is difficult to establish. The present collective preferences differ per country [4]. This implies that the use of shadow costs is meaningful at national or European level, where environmental pressure and environmental desires are more or less of a comparable order. This is not the case on a world scale.

Two possible routes for determining the shadow price
The shadow price can be determined firstly by estimating the environmental damage associated with the established emission objectives. Secondly, assuming that the government works cost-effectively, the shadow price can also be derived by combining the prevention cost with the emission objectives adopted.

Environmental damage is difficult to establish
The value (monetary) of environmental damage is difficult to establish. An approach for this is the “willingness-to-pay” principle, whereby the amount is established that society (or groups in society) can pay to avoid particular environmental damage. This can be done directly (“stated preferences”) by enquiries (contingent valuation method) or by inferring the revealed influence of the environmental burden on market prices (“revealed preferences”). The disadvantage of these methods of willingness to pay is that they are very moment-related and must be implemented simultaneously for all environmental effect categories if comparable results are to be obtained. One wonders in particular whether, for the alleged preferences, obstruction is correctly estimated, in other words in the right relationship with real investment decisions [11].

Emission prevention costs can be established more accurately
The emission prevention costs or combating costs can be established more accurately. The highest permissible cost for preventing certain environmental effects, the so-called marginal cost that society must incur if the emission objective desired by government is to be achieved, can be used as a basis. An alternative method is to resort to price elasticities, but these are available only to a limited extent. In fig. 2.1 it is assumed that the government or society is sufficiently rational to position its objective at the point of the equilibrium price *and* that the location of this point is known. In other words, that the marginal environmental damage has been quantified. This is not in fact the case, so that the shadow price derived from the present policy objective and marginal prevention curve must be interpreted more as a yardstick of present policy preferences. The shadow price is above all an estimate of the equilibrium price by present policy. Since policy-makers wish to set to work cost effectively, the consequence of the present objective is that the marginal damage is evidently estimated at the shadow price level. The actual environmental damage as perceived in society may lie at a completely different level.

CE has established the shadow prices within the Netherlands [11] for the environmental effect categories of the CML-2 method, except for six categories in the area of human toxicity, ecotoxicity and abiotic raw material depletion. It should be mentioned here that CE in fact establishes the shadow price for emission objectives for the year 2010. This can be done because the environmental effect categories that CE deals with are properly worked out and documented in policy plans and measures. This is not the case with the other topics, where objectives, insofar as they are set, often influence more than one environmental effect category. An analysis of the present situation is therefore more opportune, so the shadow price of present policy can be derived from it on the basis of the steps taken.

Overview of steps taken

The shadow prices to be used in the weighing up method for the environmental effect categories of abiotic raw materials depletion and toxicity are worked out by five stages:

1. determining present policy for the various environmental effect categories;
2. selecting relevant guide substances, sectors and firms for the policy to be implemented;
3. collecting cost data for measures by means of literature research and telephone interviews of firms, licensors and experts;
4. calculating the shadow price on the basis of the cost estimates of the measures;
5. calibrating the shadow price on the basis of environmental costs actually incurred.

Determining present policy

The present policy that is relevant to the environmental effect categories investigated is analysed to see how society is stimulated to take steps, so that they can be taken into account when selecting guide substances, sectors and measures. A look is taken here at policy: concentration standard, emissions standard, objective for emissions, concentrations or reduction in use, for firm, sector or country. Particular reference is made to national and European laws and regulations.

Selecting guide substances, sectors and firms

With this step, the relevant substances and sectors are selected where it is anticipated that measures have been adopted to comply with present policy. This selection is made with the aid of the data from Emission registration (Collective and Individual firms) coordinated by TNO each year [1]. These are converted for each environmental effect category into equivalent emissions with the aid of characterising factors in accordance with CML-2 [3].

The 1.4-dichloro-benzene equivalents used for toxicity and ecotoxicity are not comparable for the toxic environmental effect categories because the significance of the effects of a unit of 1.4-dichloro-benzene differs per environmental effect category. Dichloro-benzene equivalents of various environmental effect categories cannot therefore be aggregated. Guide substances are consequently selected separately for each environmental effect category. A selection of guide substances and sectors is made for each environmental effect category on the basis of three criteria for each substance:

1. share in national and sectoral equivalent emission;
2. historical change in equivalent emission;
3. present policy pressure to take steps.

By selecting the substances contributing most to the national or sectoral total per environmental effect category, the likelihood is enhanced that these substances will be important for the measures within a certain environmental effect category.

Substances and sectors have also been selected where an appreciable reduction has already been made and where the policy pressure to take steps is appreciable, so that we may assume that the best progress on the marginal reduction cost curve has been made here (in other words the marginal costs are high). A link is made here with the collected data on policy measures for the environmental topic concerned. A number of firms have been chosen from the selected sectors where data on the cost of measures per substance have been collected.

Collecting cost data for measures
As a third step, data were collected regarding costs and emission reductions under the measures by means of literature research and telephone interviews with selected firms, provincial authorities and experts. The ultimate objective is to establish the marginal prevention costs or the most expensive measure being introduced to achieve a reduction or equivalent reduction, because this is the shadow price.

We have had to rely heMSWIly on the data in the international literature because telephone enquiries amongst firms did not produce a great deal. Firms do not wish to let go of their data on competition grounds, have had enough of surveys or do not wish to cooperate for other reasons.

Calculating the shadow price
As a fourth step, the shadow price for a particular environmental effect category was estimated on the basis of cost data and emission reductions through measures, obtained from the literature and interviews. These are the marginal prevention costs or the most expensive emission reduction measure adopted to comply with policy. These cost data were converted to Euros per equivalent reduction.

Because many measures cover more than one environmental effect category, reduction costs in € per equivalent reduction can be calculated only if cost allocation is arranged by environmental effect categories. The following cost allocation method was therefore developed for options that influence more than one environmental effect category:
1. initial weighing up of environmental effect categories that reflect the priority of the present policy is necessary for these or the equivalents to be compared;
2. the reduction cost must effectively be allocated on the basis of the relative importance that a measure has for an environmental effect category;
3. minor environmental effects within an environmental effect category are ignored on account of their disruptive effect.

Calibrating the shadow price

Shadow prices established by the method described above for toxic environmental effect categories have proved inadequate in practice. The main reason for this is that the present toxicity policy is inconsistent with the CML-2 method used. The policy does not work precisely according to the characterisation factors of CML, partly because local and practical aspects play a role (rightly). This can reduce the cost effectiveness of measures in terms of CML characterisation factors. The shadow prices calculated are consequently not the "revealed collective preferences" of present policy. The result is that the shadow prices are so high that any application is overshadowed by the shadow cost of toxicity.

In order nonetheless to calculate a viable shadow price in DuboCalc and other instruments and analyses, the shadow prices for the various environmental effect categories have been calibrated on the basis of the expenditure incurred on distributing toxic substances according to Milieubalans (Environmental Balance) [9]. The shadow prices calculated are consequently more representative of the present policy approach. The calibration procedure is further described in Chapter 4.3 Calibration of Shadow Prices.

References

[1] EmissieMonitor/ Loketvraag, see Annex B.

[2] Guinée, J.B. et al, Life cycle assessment - an operational guide to the ISO standard, vol. I, II and III, Institute of Environmental Sciences - Universiteit Leiden, May 2001.

[3] Huijbregts, M.A.J., Priority Assessment of Toxic Substances in the frame of LCA – draft, Institute for Biodiversity and Ecosystem Dynamics, University of Amsterdam, March 2000.

[4] Huppes, G., M.D. DMSWIdson, J. Kuyper, L. van Oers, H.A. Udo de Haes and G. Warringa, Eco-efficient environmental policy in oil and gas production in the Netherlands, Project for NOGEPA, The Hague, 2002/2003

[5] Jantzen, J., Duurzame groei in Nederland? Het duurzaam Nationaal Inkomen onder Paars (1990-2000), Institute for Applied Environmental Economics (TME), June 2002.

[6] KPMG Sustainability en CE. Duurzame winst! De milieuwinst van de Groenregeling inzichtelijk gemaakt. September 2002. http://www.kpmg.nl/docs/bas_sustainability_advisory_services/rapport%20duurzame%20winst%20kpmg%20en%20ce.pdf

[7] Kroon, P., et al, Weegfactoren voor luchtverontreiniging, Systeem voor de integrale evaluatie van de uitworp van luchtverontreiniging, ECN, ECN-R--94-006, June 1994

[8] NIBE Research, Duurzaam & Gezond Bouwen, July 2002

[9] RIVM, Milieubalans 2000

[10] RIVM/EFTEC, Valueing the benefits of environmental policy: The Netherlands, RIVM report No. 481505024, Bilthoven, July 2001

[11] Soest, Jan Paul van, Hein Sas, Gerrit de Wit. Appels, peren en milieumaatregelen. Afweging van milieumaatregelen op basis van kosteneffectiviteit. CE, Delft. October 1997.