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# COMPARATIVE ENVIRONMENTAL LIFE-CYCLE ANALYSIS OF TWO PACKAGINGS FOR POTTED PLANTS

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SUMMARY

The company Voges Verpakking B.V. produces mail-order packagings for potted plants, among other commodities. The one-way packagings are made of recycled polyethylene terephthalate (PET). The base material consists of used bottles and production waste (primarily from packaging producers).
Clients have been asking whether the plastic packaging could be replaced by cardboard packaging. This would be particularly desirable from an environmental point of view. Voges Verpakking B.V. might be able to supply this, but they have not yet made a decision. For daily use, plastic packaging meets the requirements better than cardboard packaging. Thus, if Voges would make the switch to the production of cardboard packagings, this would only take place on the basis of environmental considerations. For this reason Voges Verpakking B.V. commissioned the TNO Plastics and Rubber Research Institute to investigate whether cardboard packaging is preferable, from an environmental point of view, to the packaging made of recycled PET.
In this investigation, a frequently-used PET packaging (from the assortment of Voges) is compared to the best corresponding cardboard packaging that is commercially available at this moment. As a starting point, the following functional unit has been taken: the packing of 30,000 medium-sized potted plants for mail-order delivery. As both packagings are suitable for packing three potted plants, 10,000 packagings are required in both cases.
An environmental Life-Cycle Analysis (LCA) has been performed for the packagings under study. For this purpose, the environmental impacts during the entire life cycle have been examined, from the production of base materials up to and including waste treatment. The aspects considered include the consumption of raw materials and energy, emissions of pollutants into air, water, and soil, and the space occupancy of solid waste. The environmental impacts during the generation of consumed energy and during transportation are also incorporated in this study. The data used have been obtained from Voges and subcontractors, and from public sources.

The following conclusions could be drawn from the investigation:

- Recycled materials are used for the manufacture of both packagings . Both base materials (used bottles and packaging waste for the PET packagings and waste paper for the cardboard packagings) originate from an existing collection program. No 'new' raw materials are being used in either case;
- There is a difference in the masses of the consumed raw materials, primarily caused by the different masses of the packaging itself. The PET packaging weighs 40 grams, whereas the cardboard packaging weighs 112 grams. If material losses during production processes are taken into account, there is a total material consumption of 428 kg (PET waste) for the PET packagings and 1518 kg (waste paper) for the cardboard packagings;
- For both packagings, the environmental impacts primarily occur during the production processes. The transportation and waste treatment processes contribute significantly less to the overall environmental impacts;
- The environmental impacts during the production processes primarily originate from the generation of energy;
- When comparing the environmental impacts during the entire life cycle of both packagings, the cardboard packaging appears to be connected with the most voluminous impacts on every relevant aspect (energy consumption, emissions into air and water, mass and space occupancy of solid waste);
- The more voluminous impacts of the cardboard packagings occur in each of the separate fields: production processes (including energy production), transportation, and waste treatment. The main reason for these differences is the higher mass of the cardboard packagings;
- For both packagings, a small part of the consumed energy can be recovered during waste incineration;
- This investigation started from the assumption that the packagings are being sent to locations within the Netherlands. Besides, the assumption was made that the packagings would end up as municipal waste. However, it is possible that the cardboard packagings are being recycled after use. A short investigation was made into the influence of changes in the situation with regard to waste treatment of the cardboard

packagings and to the locations to which the packagings are sent. In both cases the conclusions of this investigation would not change significantly.

It should be remarked that the conclusions relate to the two packagings under study. These packagings are suitable for medium-sized potted plants. However, there is no reason to assume that the results of this investigation would deviate significantly for differently sized packagings. For packagings with other dimensions, the higher mass of the cardboard packagings would also lead to higher environmental impacts than would be the case for the corresponding PET packaging.
From an environmental point of view, cardboard packagings could only compete with recycled PET packagings if the mass of this cardboard packaging would be significantly reduced. However, the question whether this would be practically attainable is not under discussion in this investigation.

On the basis of the results of this investigation, the conclusion can be drawn that, from an environmental point of view, recycled PET packaging is preferable to cardboard packaging. Consequently, under the present circumstances, the switch from packagings made of recycled PET to cardboard packagings for potted plants would not result in an improvement with respect to the environmental impacts.

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# 1 INTRODUCTION

Voges Verpakking B.V. produces packagings for mail-order potted plants, among other things. The most important clients for these packagings are mail-order firms for potted plants. Voges has been producing these plastic packagings for about 25 years. Until 1987, polyvinylchloride (PVC) had been used. From that time, resistance arose against the use of this plastic material in (one-way) packagings. Therefore, since 1987, the packagings have been made of recycled polyethylene (PET). The base material is supplied by a company that collects, cleans, and grinds waste PET. Other companies process these grains into foil, which is processed by Voges into packagings by thermoforming.

The last few years have witnessed a growing resistance against the use of any plastic material in packagings. Consumers are urging producers to replace PET by cardboard, as this latter material would be less harmful from an environmental point of view. In addition, financial pressure arose in Germany to replace plastics in packagings by, for instance, cardboard and paper. The fact is that the environmental policy in Germany has imposed levies on packaging materials, with the levy on plastics (per kg of material) being about eight times as high as the levy on paper and cardboard.

In the recent past, an important customer of Voges Verpakking tried some cardboard packagings. This led to the conclusion that, for daily use, plastic packaging is preferable to the cardboard packaging, as plastic packaging is stronger and more moisture-retaining and is easier to handle. These advantages are so important that cardboard packaging for potted plants has found little application up to now.

At this point in time, Voges has not yet decided on the material to be used. The choice primarily depends on whether cardboard packaging really is better, from an environmental point of view, than PET packaging. Apart from the financial pressure (an argument which as yet only holds for Germany), this would be the only argument in favour of cardboard packaging.

In order to investigate whether cardboard packaging is better than packaging made of recycled PET, used up to now, Voges Verpakking B.V.

commissioned the TNO Plastics and Rubber Research Institute to perform a comparative environmental Life-Cycle Analysis of two packagings for potted plants. From the approximately 80 packaging products that are produced by Voges, one frequently used packaging has been selected. Three potted plants can be packed in this one-piece packaging. A comparable type of cardboard packaging has also been investigated. Three potted plants of the same size can be packed in this one-piece packaging as well.

For both packagings, an inventory will be made of the raw materials and energy consumption during the production of the base materials, and during the manufacture of the packagings from the base materials. An inventory will also be made of the emissions into air, water, and soil during the separate phases in the life cycle of the products. In this way, production, use, and waste treatment of the packagings under study will all be considered. The energy consumption and emissions during various transportation processes in the life cycle will be included as well.

This investigation will use general information, already present at TNO, along with more specific information which has been made available by Voges Verpakking and subcontractors.

If the results of this investigation permit, it will be determined, from an environmental point of view, whether there is a preference for one of the packagings under study.

## 2 PLAN OF INVESTIGATION AND REPORTING

The following chapters will first provide some information on environmental life-cycle analysis (LCA). The state of the art with respect to formulating of an international standard in this field will be indicated as well. Next, the problems will be discussed that occur while performing an LCA and interpreting the results.

After that, the boundaries of the system to be studied will be determined for both packagings, i.e. it will be examined which elements will be part of the investigation and which elements are not significant in this case. Then, the life cycle of each packaging will be divided into the sub-processes (including transportation) that are conducted during production, use, and waste treatment. This yields a so-called process tree for both packagings.

Subsequently, the environmental impacts during the life cycle will be determined for both packagings. Here a distinction will be made between environmental impacts that occur during production processes (including the generation of the required energy), during transportation, and during waste treatment. Finally, an overall view will be given in which the environmental impacts during the entire life cycle have been added.
The advantage of this presentation method is that the packagings cannot only be compared on the overall environmental impacts during the entire life cycle, but also in some separate fields (production, transportation, and waste treatment). If it becomes apparent from the overall view that the use of one of the packagings is connected with significantly greater environmental impacts than the use of the other packaging, it will be possible, with the aid of the partial overviews, to trace to which separate field (or fields) this difference can be attributed. In the case of optimizing the relevant packaging, this specific field should be the first to be improved.

# 3 ENVIRONMENTAL LIFE-CYCLE ANALYSIS

## 3.1 General considerations

An environmental life-cycle analysis (LCA) evaluates the environmental burdens connected with the functioning of a product (eventually a process or activity). Thus, only environmental impacts are studied; no attention is paid to the economical aspects or aspects concerning handling or convenience of use. An LCA covers a broader area than may be expected on the basis of this description. Not only is the phase of use of the product considered, but also the production phase and the disposal phase. In other words, it covers the entire life cycle of the product.
LCA's may be applied by various users and for various purposes. For instance, the government may use an LCA as a political instrument. An LCA may be used to determine the environmental burden of a certain product. It may subsequently be decided if the application of this product should be stimulated or not. LCA's may also be used by manufacturers who want to evaluate the environmental burden of some of their products. Using an LCA, they can also determine the main areas of environmental impact that occur during the manufacture of a certain product. In the case of optimization, this part offers the best options for improvement. It is also possible to calculate the environmental impacts of some products during the design stage. The environmental burden of each design could be considered when a decision on the final design is to be made. Finally, a consumer will be able to examine the environmental aspects of some products already on the market. These aspects can be considered when making a choice between these products.
Performing an LCA is only meaningful if the results can be compared with the results of other LCA's. This makes it necessary to follow a standard procedure that can count on a broad consensus. In the past, there has hardly been any agreement in this field. Nowadays, much work is being done on a national and on an international scale (including The Society of Environmental Toxicology and Chemistry, The European Centre for Plastics in the Environment) in developing a generally accepted methodology. In the following sections, a brief overview will be given of the essential aspects of this methodology and on the state of the art in

this field. More comprehensive information on LCA's and on the LCA methodology can be found in ref. 1 to 4.

## 3.2 The functional unit

LCA's are often used to compare products that have similar functions. The question whether the environmental burden of a product should be assessed as high or low can in most cases only be answered in a meaningful way if it can be compared with the environmental burden of similar products.
An important aspect of an LCA is indicated when mentioning the term 'functional unit'. This emphasizes the performance of a product. The term 'performance' may refer to very divergent matters, such as the packing of 1,000 litres of soft drinks, the freezing of 1,000 kg of meat products, the transportation of 100 tons of ore over a distance of 1,000 km, etc.
In a comparative LCA, different products are never simply compared to each other; the comparison should always be made on the basis of the performance of the products. This performance is indicated by the term **functional unit**. Once the functional unit has been determined, the definitive setup of the comparison can be determined.
An example of the above is the comparison between milk packagings and milk bottles. A comparison is only meaningful if the performance of both packagings has been taken into account. Milk packaging is a one-way type of packaging, whereas a milk bottle may be used several times. Thus, if in this case the functional unit is fixed at 'the packing of 1,000 litres of milk', on the one hand, 1,000 milk packagings are needed, whereas on the other hand only 40 milk bottles may be required. However, before a milk bottle can be used again, it has to be returned to a central location and cleaned. This means that, in the investigation of the bottles, 25 return trips and 25 cleanings have to be taken into account as well. These aspects are not involved in the investigation of the milk packagings.

## 3.3 Inventory analysis

When the functional unit has been determined and the resulting setup of the comparison is clear, the process trees to be compared are drafted. As was stated briefly in chapter 2, the life cycle of each of the investigated products is divided into the base processes (including transportation) that are conducted during production, use, and waste treatment.

After that, an inventory is made of each base process, including the following environmental impacts: raw material consumption, energy consumption, and emissions into air, water, and soil. For both packagings, an overall view of the environmental impacts during the entire life cycle can be obtained by adding the environmental impacts of the base processes.

When collecting the required data, the scope of the LCA should already be taken into account. For example, if a manufacturer intends to examine some of their products, they will have to use information that refers to their own production processes. This information is specific to one particular process and one particular plant. However, if the Dutch government wants to gain insight into the environmental burden of a specific product that is being produced by several manufacturers in the country, data are required that refer to the average situation in the Netherlands.

Therefore, when collecting data for each base process, it has to be taken into account to which situation these data apply. Depending on this criterion, a search can be made for specific data (for a certain plant or branch of industry) or for more general data (average data for the Netherlands, Western Europe, the EEC, etc.).

Up to now, a major bottleneck conducting LCA's has been the limited availability of reliable environmental data on industrial processes. As far as the Dutch situation is concerned, relatively much information is available. From the beginning of the eighties, emission data on various industrial processes have been collected by employees of the TNO Group Emission Registration. On a European level, the generation of environmental data is well underway, especially in the plastics industry. In addition, information on various fields has become available from several sources (mainly the national governments). However, there is still no question of complete and reliable information on all industrial processes, and the methods of information collection are not yet uniform. As a consequence, during the inventory analysis, relatively much time is required for the collection of relevant information and (if possible) validation of the acquired data with the help of reference data.

## 3.4 Classification

The object of a classification is to connect the actual environmental impacts (consumption of raw materials and energy, emissions) with the environmental burden. For this purpose, the broad term 'environmental burden' has been divided into several parts that have been designated as impact categories. At present, the following impact categories have been distinguished:

- global warming;
- ozone depletion;
- photochemical oxidant formation;
- acidification;
- eutrophication;
- human toxicity;
- depletion of resources;
- space occupancy (e.g. by solid waste).

In some cases, this list may be extended by local environmental impacts, such as stench or noise pollution.

For every environmental impact (e.g. the emission of nitrous oxides), it is investigated to what extent this impact contributes to each of the above categories.

It is quite possible that a certain impact contributes to a number of impact categories. For instance, nitrous oxides contribute to human toxicity, acidification, and eutrophication. The impact has an index for each relevant category, indicating to what extent this impact contributes to the category in question.

In this way, the contributions to all relevant impact categories can be calculated for all environmental impacts listed in the inventory. This yields a brief table which reflects the consequences of the functioning of the product under study during its entire life cycle, for each environmental impact category. This provides the impact profile of the product.

It is clear that an extensive classification system is required, as each emitted substance should have an equivalence factor for each relevant impact category, indicating to what extent this emission contributes to the impact category in question. Thus, nitrous oxides should have equivalence factors for human toxicity, acidification, and eutrophication. At present, several departments (on a national and an international level) are working on the development and use of these factors. As there are some tens of thousands of compounds that may be emitted during industrial processes, it is clear that this is an extensive process. At this moment the list is not definitive, and the methodological problems are certainly not resolved. As a consequence, the classification system is not yet ready for application.

## 3.5 Evaluation

For some choices and decisions to be made on the basis of a life-cycle analysis, it is necessary to conduct an aggregation that goes even further than the classification step. In this process, indicated as the evaluation, the different specific impact categories are weighted so that they can be compared. This may ultimately lead to one single figure which reflects the environmental burden of the product under study. However, the weighting of different impact categories is always subjective: the question whether global warming is a greater problem than space occupancy will contain a political decision, which may differ between countries. Apart from that, the preceding classification has not yet been elaborated sufficiently. As a consequence, an evaluation cannot be made yet.

## 3.6 State of the art

As became apparent in the above, all aspects of LCA methodology have by no means been elaborated satisfactorily at this moment. Although there is a growing consensus on the methodology and on its application, both subjects are still under discussion. In general, the first phases of the LCA methodology have been reasonably settled, but for the latter phases this is certainly not the case.
In the LCA's performed at TNO, the standard procedure has been followed up to and including the inventory analysis. In comparative LCA's this yields an overview of the consumed raw materials and energy, and of the emissions into air, water, and soil, for each of the products under study. As has been stated in the foregoing, there are no systems available yet which allow the weighting of the effects of the environmental impacts. Therefore, it is only possible to make a comparison between the different products on each single aspect. This may easily lead to a situation in which it is impossible to state which of the products under study is preferable from an environmental point of view. Such a conclusion may only be drawn if one of the products is better than the other ones on all (or by far the most) aspects.

# 4 GENERAL CONSIDERATIONS ON THIS INVESTIGATION

## 4.1 The functional unit

As stated in the foregoing chapter, a comparative LCA always starts with the performance of the product. In this investigation 'the packing of 30,000 medium-sized mail-order potted plants' has been chosen as the functional unit. In this case, 'medium-sized potted plants' are plants in pots with a length and width of about 6 cm and a height of about 7 cm. The free space above the pot, which is available for the plant, is about 8 cm.

Of all the packagings that are produced by Voges the model which is indicated as no. 30888 may be used for this purpose. The mass of this one-piece packaging is 40 grams; three potted plants can be packed in one packaging. Cardboard packaging with comparable dimensions is available on the market. The mass of this packaging (also one-piece) is 112 grams. This packaging is suitable for three potted plants as well.

Both cases involve a one-piece packaging, which can be disposed as domestic waste. Thus, a comparison can be made between 10,000 packagings made of recycled PET and 10,000 packagings made of cardboard. The comparison must include the entire life cycle of the packagings, meaning that the environmental aspects of production, use, and waste disposal all have to be examined.

## 4.2 System boundaries

### 4.2.1 Environmental aspects of raw material acquisition

Only waste paper is used as a raw material in the cardboard packaging, whereas only recycled PET is used in the plastic packagings.

In these cases, it is always questionable whether the production of new material has to be taken into account or not. When the 'first' product (i.e. the product that is made from new material) has been designed and manufactured, taking into account the future reuse of the material, then it is reasonable to only partially allocate the environmental impacts of the production of the base material to this first product. Some of these impacts can be allocated to the following products that are manufactured with the reused material.

This issue is important, as the environmental impacts that are connected with the production of new materials are frequently more voluminous than the impacts connected with the following production processes. For instance, when making an inventory of the environmental impacts during the production of a plastic item, it often becomes apparent that these environmental impacts are primarily connected to the production of the plastic material, whereas significantly smaller impacts should be allocated to the manufacture of that item from the plastic material. This is not surprising, because the production of plastic materials consists of numerous base processes, starting from the extraction of crude oil (and eventually other raw materials) up to and including polymerization. This also holds for the production of paper. The production of new paper is connected with relatively voluminous environmental impacts, when compared to the reuse of waste paper.

In this investigation, no contribution from the production of new materials has been taken into account during the inventory analysis, as in both cases products are involved that do not need materials which have been used only once before. In the case of reused materials, there is nearly always a decay of properties as they have been reused more often. As a consequence, for some applications, a material is required that has been used only once before; material that has been used more often is no longer suitable. The material in such an application is at the beginning of the product chain, therefore, it is reasonable to allocate some of the environmental impacts of the new material to this application.

However, for packagings for potted plants, materials may be used that have been used numerous times before. For the cardboard packagings, old newspapers are used which have been made of waste paper themselves. Some of the material from which the plastic packagings have been made have only been used only once before (see the following chapter). However, for this application, this is certainly not necessary. The use of this base material is dictated by the market situation and not by material requirements. Some of the products are made of PET material that has been used several times before. If necessary, the production may be conducted entirely with material that has been used many times before. The

requirements for the material from which the packagings for potted plants are being made are so low that any recycled PET may be used.
In view of the low material requirements, in both cases, materials may be used that are at the end of the product chain (the base material may have been used numerous times before). In such cases, no contribution from the production of new materials has to be taken into account.

### 4.2.2 Environmental aspects of waste treatment

A similar question arises at the end of the life cycle, during waste disposal. As the materials have been used several times before, it is questionable whether the environmental impacts during waste treatment should only be allocated to the last application. In this investigation, this has been done for both packagings. It appears that, in practice, the packagings are handled as domestic waste. Although it is possible to collect the plastic packagings separately from other domestic waste and to reuse them (as is the case with production waste), in practice, this is not yet feasible.
For cardboard packagings, there are more possibilities for separate collection and material reuse. Although no specific information is available concerning consumer behaviour with respect to packagings for potted plants, it is usually assumed that these kinds of packagings are treated as domestic waste, which means that they are being dumped or incinerated.
The environmental impacts accompanying this kind of waste treatment will be allocated entirely to the cardboard packagings. Apart from that, a calculation will be made dealing with a situation in which half of the cardboard packagings are reused, while the other half is treated as domestic waste. In chapter 7, the influence of this alternative scenario on the overall environmental impacts will be discussed. In this way, the influence of potential variations in waste treatment on the entire life cycle analysis of the cardboard packagings can be estimated.

### 4.2.3 Specification of examined aspects

When performing an LCA, it is important to examine which aspects will be taken into account and which aspects will be left out.

This investigation will consider the environmental impacts during production and waste treatment, as well as the transportation processes (the use of the packagings is not connected with any environmental impacts). The following aspects will not be taken into account:

- manufacture of 'secondary' packaging materials, such as the bales in which the base materials are transported, the film in which paper rolls are packed during transportation, the pallets on which bales and rolls are transported;
- the environmental impacts that are connected with the use of adhesives in the cardboard packagings. The amount of glue is low and, in view of the nature of these adhesives (frequently natural materials), the environmental impacts will have no significant contribution to the overall result;
- manufacture of production machines;
- heating of workrooms.

In these cases, only small impacts are involved. They may virtually always be considered negligible when compared to the impacts that are directly connected to the production, use, and waste treatment of the actual products. Besides, most of these impacts will be equal for both packagings under study. Therefore, there is no objection against excluding these aspects for both packagings.

## 4.3 Environmental impacts during electricity generation

As stated in the foregoing, the environmental impacts during the generation of the consumed energy will be taken into account in this investigation.

In many cases, electrical power is involved which is extracted from the public network. This electrical power may be generated in several ways: by the combustion of fossil fuels (coal, lignite, oil, natural gas), in nuclear processes, by water power, etc. In almost all cases, a compound process will be involved: the electricity supplied by the public network is generated by several processes.

The environmental impacts during electricity generation depend on the applied fuels and processes. As this situation may differ strongly between countries, the environmental aspects of electricity generation greatly depend on the country where this generation takes place.
The production processes of the packagings under study take place in the Netherlands and in Germany. In the Netherlands, electricity is primarily generated by the combustion of natural gas (54%) and coal (35%); in Germany, coal (49%) and nuclear fuels (33%) are used (situation of 1990 (3)). Therefore, there are significant differences between the environmental impacts.
Although it is possible to use data concerning the situation in both countries separately, another approach has been selected in this investigation. It is true that the use of data which are specific for the Netherlands and Germany will yield results which adequately reflect the present situation, but these results will have limited validity. It could be possible, for instance, that Voges Verpakking B.V. will produce the cardboard packagings for itself. In that case the production will primarily take place in the Netherlands, whereas the results presented here refer to the German situation.
It may also be possible that Voges will buy from other subcontractors in the near future. In this scenario, some of the processes discussed here will take place at other locations. In each of these cases, the situation concerning electricity generation will deviate significantly from the situation discussed here. This may have major consequences for the conclusions of this investigation, concerning the environmental impacts that are connected with the packagings under study.
In order to make the results of this investigation less susceptible to the above-mentioned variations, the environmental impacts during electricity generation have been derived from a model which reflects the average West European situation. This model considers the average situation in the twelve countries that were united in the UCPTE (a cooperative body which coordinates the generation and transportation of electricity in the member countries) in 1988. For this reason, the model is indicated as the UCPTE 88 Model. Appendix A provides a brief description of this model. The environmental impacts during electricity generation according to this model are presented there as well.

# 5 COMPARISON OF PRODUCTS AND PROCESSES

## 5.1 Introduction

This chapter will provide an inventory of the processes which take place during the life cycle of the packagings under study. In the preceding chapter, it was outlined that packaging no. 30888 (mass 40 grams), produced by Voges, will be compared to a similar type of cardboard packaging (mass 112 grams) which is available on the market. Three medium-sized potted plants may be packed in both packagings. A total of 10,000 pieces of each type of packaging will be considered.
The inventory of processes will include the production of base materials, semi-products, and products, and waste treatment processes.
Transportation processes during the life cycle will be considered as well. A process flow-chart will de drafted using these base processes. This process flow-chart will serve as the starting point for the calculations of the environmental impacts during the life cycle of the packagings.

## 5.2 Process flow-chart for packagings made of recycled PET

### 5.2.1 Origin of the base material

The packagings for potted plants are made of base materials from several sources. In each case, the material has been used before in other applications.
The main base material is PET, coming from the existing deposit system for bottles. After use, the bottles are returned to the fillers. Some of these fillers have a contract with the company that processes these bottles into the base material which is used for the production of the packagings. The reprocesser is located in the Netherlands.
The base material coming from the reprocesser is delivered to two film manufacturers, who mainly use this material in their production processes. It is replenished by other industrial PET waste: one producer mainly uses waste cuttings from several packaging manufacturers, the other producer uses waste originating from the manufacture of PET bottles. This industrial waste is added to the process without any preprocessing.

The third base material source is the Voges company itself. The material that is supplied by the film manufacturers is processed into packagings for potted plants by Voges, resulting in about 15% waste cuttings. These waste cuttings are reprocessed by a third film manufacturer into film, which is again used by Voges in the production of packagings. No other base materials are used in this film production.

### 5.2.2 Reprocessing disposed PET bottles

The PET bottles from the deposit system are reprocessed to a base material that can be used in several other applications. The following takes place during this reprocessing:

- intake and quality control (removing bales which are not on the purchase specification);
- debaling, removing large contaminants;
- label separation;
- visual check, removing coloured material, PVC, etc.
- metal detection, removing metal parts;
- grinding;
- washing;
- glass and heavy particle separation;
- separation of polypropylene, polyethylene, etc.
- dehydration and drying;
- metal detection, removing metal parts;
- quality control, removing material which does not meet quality specifications;
- bagging.

During this reprocessing there is approximately an eight percent material loss due to the removal of adhesives, labels, and dirt. This material is assumed to be dumped.

During reprocessing, the caps are separated from the bottles. These parts, mainly made of high density polyethylene, are reprocessed to grains. The environmental impacts that take place during the reprocessing of bottles and caps are allocated to both kinds of grains on a mass basis.

Both electricity and steam are used during the reprocessing of PET bottles. This investigation starts with the assumption that heavy fuel oil is used for steam generation.

### 5.2.3 Production of film

The grains coming from the bottle reprocesser are processed into film in an extrusion process. During extrusion, the grains, together with industrial PET waste, are fed into a hopper which empties into a horizontally placed cylinder. A screw rotates in this cylinder, thus uniformly transporting the material. The cylinder is heated to the extent that material melts during transport. The plastic mass leaves the cylinder through the outlet opening: a wide slit. After leaving this opening, the material is transported and cooled across a series of rollers. Frequently the rotation speed of the rollers is significantly higher than the speed of the molten polymer, causing a certain thickness reduction (5).
As stated above, Voges buys the film from two different manufacturers. The first manufacturer (indicated as manufacturer A) states that no material loss occurs during production. Any waste is immediately returned to the process. The second manufacturer (manufacturer B) reports about an eight percent material loss. Most of this waste is returned to the process. Finally, one percent waste remains, which is then dumped.
The film that is produced by the third manufacturer (manufacturer C) is made of waste cuttings from the packaging production. No losses occur during the extrusion of this material.

### 5.2.4 Production of the packagings for potted plants

The packagings are produced from film by thermoforming. In this technique, a sheet or a film is moulded into the desired product. In some moulding techniques, the plastic film is pressed between two mould halves, so that the film is mechanically forced into the desired shape. However, in thermoforming, the film is pressed onto one mould form. The plastic film is placed in a hollow mould. Subsequently, the air between the mould and the film is removed by a suction pump, after the material has been heated to above its softening point (usually by infrared heaters). After cooling, the product is removed from the mould. This process usually takes place in completely automated thermoforming machines (5).

### 5.2.5 Other processes

All relevant processes that take place during the production phase have been discussed. However, there are some other relevant processes. In the first place, several transportation processes are involved. As became apparent in previous sections, the transportation of base materials and semi-products takes place between the production processes. During these transportation processes, energy is consumed (in the form of fuel) and emissions into air occur.
After manufacture, the packagings are transported, for example, to a mail-order firm, after which they are transported (filled with potted plants) to the buyer of the plants. The use of the packagings is not connected to any environmental impacts, but the transportation processes should of course be taken into account.
After use, the packagings are disposed of as municipal waste, which means 60% landfill and 40% combustion. In both cases, transportation takes place (to the dumping site or the incinerator). The environmental aspects of waste treatment should also be considered.

### 5.2.6 Overall process flow-chart for packagings made of recycled PET

The process flow-chart for packagings made of recycled PET can now be drafted. This flow-chart is presented schematically in Figure 1. This figure shows the actual amounts of raw materials, semi-products, and products. The magnitude of each transportation distance is also provided. The allocation of the film production over the film manufacturers is based on a practical situation.
The magnitude of the transportation processes is determined on the basis of the geographical location of, for example, the manufacturers in question. In those cases where an exact location was unknown, an estimation was made.

- The used PET bottles are transported from several locations to the reprocesser. The distance has been determined on the basis of an average situation (100 km) in the Netherlands.

- The two film manufacturers who deliver to Voges mainly buy their base material from the bottle reprocesser. Manufacturer A, which makes 70% use of the ground PET material, is located at a distance of 200 km from the bottle reprocesser. Manufacturer B, which makes 80% use of ground PET material, is located at a distance of 140 km from the bottle reprocesser.
  The remaining 30% and 20% respectively, comes from several PET processing companies. The transportation distance between these companies and the film manufacturers has been estimated at 150 km.
- The film manufacturers deliver their products to Voges. Manufacturer A is located at a distance of 210 km from Hillegom (the place of business of Voges Verpakking B.V.), the distance between manufacturer B and Hillegom is 90 km.
- Voges' production waste (15% of the processed amount) is reprocessed into film by film manufacturer C, without any material losses. The film is returned to Voges over a distance of 220 km.
- The packagings for potted plants are filled by several mail-order firms and subsequently sent to the buyers of the plants. The total distance has been estimated at 100 km. This case takes into account the fact that the main clients are located near Voges. It is also assumed that the plants are sent to locations within the Netherlands. If the sales take place in other countries, this will of course have an effect on transportation (longer distances) and waste treatment (foreign situation). It is expected that this will not change the general conclusions of this investigation. The discussion in chapter 7 will examine whether this expectation is realistic.
- After use, the packagings are disposed of as municipal waste, which means they are dumped or incinerated. A transportation distance of 50 km has been assumed in both cases.

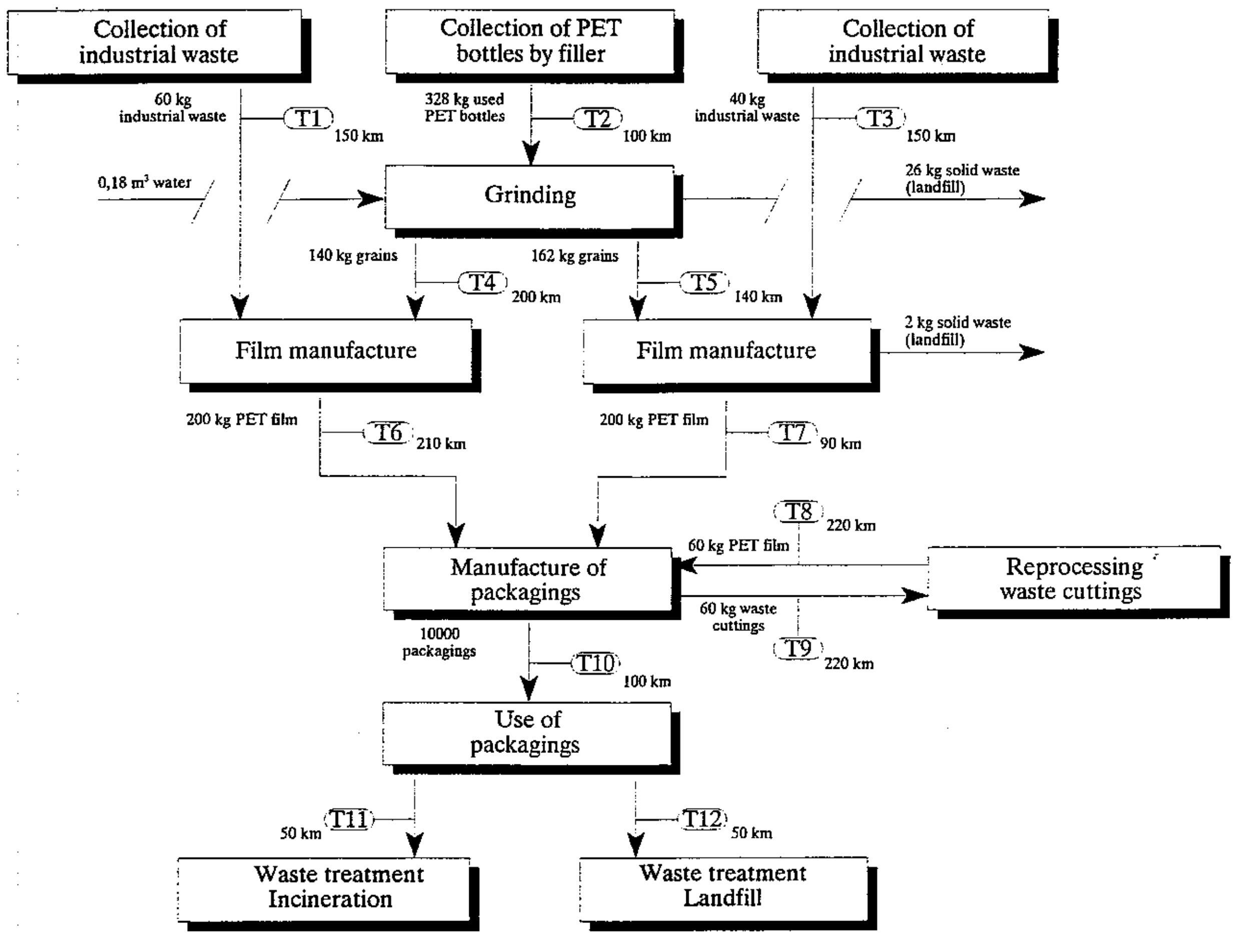


Figure 1: Process flow-chart for packagings made of recycled PET.

## 5.3 Process flow-chart for cardboard packagings

### 5.3.1 Origin of the base material

Due to increasing consumer spending, changes in demographic patterns, increases in printed information, and the demand for the transportation of commodities, paper and cardboard consumption is increasing proportionally. As a consequence, there is more waste paper, which can be used for the production of paper and cardboard for packagings.
Cardboard packagings are entirely made of waste paper, the process flow-chart of which is presented in Figure 2. The waste paper industry collects waste paper via industrial sectors and via collection by schools, clubs, and individuals. Then the waste paper is graded and baled or directly sent in containers to paper and cardboard mills.
The mill which makes the cardboard for the packagings under study is located in the east of Germany. The average transportation distance between the collector and the paper mill is 150 km. It is assumed that transportation takes place by heavy lorries.

### 5.3.2 Manufacture of cardboard

Waste paper usually consists of a mixture of several fibre types which have been reprocessed one or more times. In addition to fibres, the waste paper contains numerous compounds, such as fillers, resin glue, starch, sizing agents, coatings, etc. Several objects are often found in waste paper which have nothing to do with the waste paper itself, such as plastic, rope, staples, paperclips, etc. Due to these unusable materials in waste paper, the purification process requires meticulous attention.
The manufacture of cardboard starts with the fiberization or suspending of the fibrous materials into a watery slurry. The hard, dry bales of waste paper have to be broken down thoroughly, which means that they have to be suspended completely in water. In itself, this is an easy process, as it is only a matter of adding water and energy to the fibres.
The water slightly loosens the fibres, and the energy supplied by the rotor in a pulper almost completely releases the fibres. Finally, this process yields a paper slurry which can be transported by a pump. The water that is used in this water is not fresh tapwater, but used water

from the cardboard machine. In the manufacture of cardboard, the water is reused to a high extent to minimize the consumption of fresh water. Possible contaminations are removed in the cleaning line, after which the cleaned fibre pulp is pumped to the cardboard machine after further dilution. Fresh water is used in the cleaning line and in the dilution. In the cardboard machine, fibre layers are built up to cardboard of the desired thickness (600 g/m$^2$), and the water content is reduced from 99% to about 10%. For this purpose, wet and very thin fibre layers are pressed onto each other on a couching board, during which partial dehydration takes place. After pressing, the cardboard has a water content of about 55%. The released water is reused in the process. Excess water is stripped from usable fibre material (for reuse) and is discharged into the drain via a water purification plant.
Subsequently, the cardboard is dried on steam-heated cylinders in a drying line and the evaporated water is discharged. The steam is generated by heavy fuel oil.
Finally, the cardboard band is cut into the desired size (sheets). These sheets are then transported to the cutting plant, located in the Netherlands, to be cut and folded into packagings for potted plants. The transportation distance between the cardboard mill and the cutting plant is about 550 km.

### 5.3.3 From cutting the packagings to waste treatment

In the cutting plant, 10,000 packagings are cut from 2,500 cardboard sheets. This process produces 195 kg of cardboard waste which is disposed of as waste paper. Small amounts of adhesives are used during the manufacture of the packagings. These processes only consume electric energy.
After manufacture, the packagings are transported to several clients, after which they are transported (filled with potted plants) to the buyers of the plants. No environmental impacts are connected to the use of the packagings, but the transportation processes have to be taken into account. The total transportation distance (e.g. from cutting plant via mail-order firm to the buyer of the potted plants) is assumed to be 100 km.

After use, the packagings are disposed of as municipal waste, which means 60% landfill and 40% incineration. A transportation distance of 50 km is assumed in both cases.

5.3.4 Overall process flow-chart for cardboard packagings

The process flow-chart of the cardboard packagings can now be drafted. This flow-chart is presented schematically in Figure 2. This figure shows the actual amounts of raw materials, semi-products, and products, and the magnitude of every transportation distance.

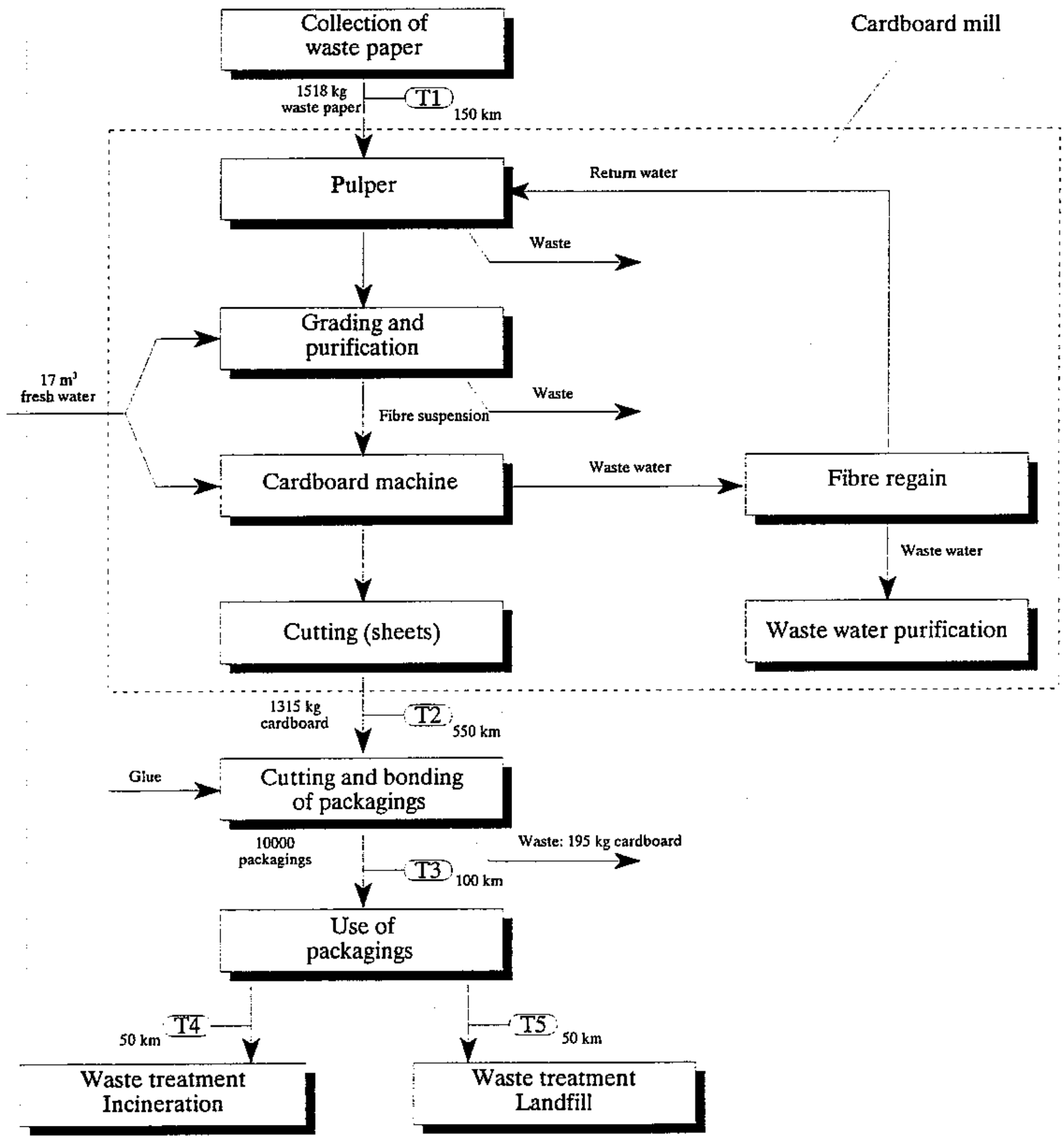


Figure 2: Process flow-chart for cardboard packagings.

# 6 ENVIRONMENTAL IMPACTS DURING THE LIFE CYCLE OF THE PACKAGINGS FOR POTTED PLANTS

## 6.1 Introduction

An important factor in LCA's is usually the raw material consumption. In this respect, the consumption of non-renewable raw materials (such as crude oil) is of major importance. As in this case no direct use is made of non-renewable raw materials, this aspect is not applicable here.
The most important environmental impacts during the life cycle of the packagings under study consist of emissions (during production processes, energy generation, transportation of base materials, semi-products, products, and waste, and during waste treatment) and energy consumption. An inventory of both packagings will be presented in the following sections, distinguishing between production processes (including energy generation), transportation, and waste treatment. For each of these separate fields, the environmental impacts will be presented in tabular form, with the impacts connected with the PET and cardboard packagings being placed in separate columns. At the end of this chapter, an overview will be given of the environmental impacts that take place during the entire life cycle of the packagings.

## 6.2 Environmental impacts during the production processes

During the production of the packagings from recycled PET, no direct emissions into air occur. However, there are emissions into water. In these processes, there are only emissions into air during the generation of energy. The processes use electrical energy and steam (thermal energy).
During the production of cardboard packagings, no emissions into air occur, although there are emissions into water. In addition to this, emissions into air occur during electricity generation and during the generation of process steam.

Table 6.1 indicates at what points in the life cycle of the PET packagings energy is consumed and what amounts of energy are involved. Table 6.2 does the same for the cardboard packagings.

Table 6.1: Energy consumption during the production of 10,000 packagings of recycled PET.

| Process | Electrical energy (kWh) | Thermal energy (GJ) |
|---|---|---|
| Repr. used bottles into film | 72 | 1.24 |
| Film manufacture | 224 | |
| Production of packagings | 143 | |
| Repr. waste cuttings into film | 34 | |
| Total consumption in production | 473 | 1.24 |

Table 6.2: Energy consumption during the production of 10,000 cardboard packagings.

| Process | Electrical energy (kWh) | Thermal energy (GJ) |
|---|---|---|
| Repr. of waste paper into cardb. | 778 | 12.18 |
| Cutting and bonding of cardboard | 61 | |
| Total consumption in production | 839 | 12.18 |

Table 6.3 indicates what amounts of energy are consumed during the production of 10,000 packagings for potted plants and what emissions take place during these processes (including emissions during energy generation). The information in Appendix A has been used for this table.

Table 6.3: Environmental impacts connected with the production of 10,000 packagings for potted plants.

| | | Packaging material | |
|---|---|---|---|
| Energy consumption | Unit | Recycled PET | Cardboard |
| Electrical energy | MWh | 0.47 | 0.84 |
| Thermal energy | GJ | 1.24 | 12.18 |
| Emissions into air | Unit | Recycled PET | Cardboard |
| Aerosol | kg | 0.09 | 0.37 |
| CO | kg | 0.16 | 0.34 |
| $CO_2$ | ton | 0.29 | 1.29 |
| Hydrocarbons | kg | 0.02 | 0.10 |
| $NO_x$, as $NO_2$ | kg | 0.83 | 3.53 |
| $SO_2$ | kg | 1.90 | 9.97 |
| Emissions into water | Unit | Recycled PET | Cardboard |
| BOD (*) | kg | 0.04 | 0.62 |
| COD (**) | kg | 0.17 | 1.62 |
| Solid substances | kg | 0.11 | 0.39 |
| Solid waste | Unit | Recycled PET | Cardboard |
| PET | kg | 28 | |
| Cardboard | kg | | 195 |

(*) BOD: biological oxygen demand
(**) COD: chemical oxygen demand
The biochemical oxygen demand (BOD) is the quantity of oxygen that is consumed by micro organisms when decomposing the organic substances that are present in water. Thus, the BOD gives information on the quantity of biologically decomposable material in water and on the decrease in the oxygen content of water when these substances are decomposed biochemically.
The chemical oxygen demand (COD) is comparable with the BOD. The COD gives information on the quantity of anorganic material in water. It indicates how much oxygen is consumed when these substances are decomposed chemically.

## 6.3 Environmental impacts during transportation processes

During the life cycle of the packagings, some transportation processes take place. Energy is consumed during transportation and emissions into air occur during energy generation. The nature and amount of the consumed energy and the emissions depend on the transportation distance and the means of transport. Only heavy lorries have been used in the transportation processes of both packagings under study. Data from the Netherlands Central Bureau for Statistics (7) have been used for the calculation of the environmental impacts during transportation by heavy lorries. These data are based on the situation in the Netherlands in 1991 which does not deviate significantly from the German situation.

Table 6.4 presents the transportation processes during the life cycle of the plastic packagings. Table 6.5 does the same for the cardboard packagings.

Table 6.4: Transportation processes during the life cycle of 10,000 packagings made of recycled PET. The indications in brackets refer to Figure 1.

| Transportation process | | Mass (kg) | Distance (km) | tons•km |
|---|---|---|---|---|
| PET bottles to reprocesser | (T2) | 328 | 100 | 32.8 |
| Industrial waste to film manuf. A | (T1) | 60 | 150 | 9.0 |
| Grains to film manufacturer A | (T4) | 140 | 200 | 28.0 |
| Film A to manufacturer packagings | (T6) | 200 | 210 | 42.0 |
| Industrial waste to film manuf. B | (T3) | 40 | 150 | 6.1 |
| Grains to film manufacturer B | (T5) | 162 | 140 | 22.6 |
| Film B to manufacturer packagings | (T7) | 200 | 90 | 18.0 |
| Waste cuttings to film manufact. C | (T9) | 60 | 220 | 13.2 |
| Film C to manufacturer packagings | (T8) | 60 | 220 | 13.2 |
| Packagings to customers | (T10) | 400 | 100 | 40.0 |
| Waste to incinerator | (T11) | 160 | 50 | 8.0 |
| Waste to dumping site | (T12) | 240 | 50 | 12.0 |
| | | Total amount of tons•km: 244.9 | | |

Table 6.5: Transportation processes during the life cycle of 10,000 cardboard packagings. The indications in brackets refer to Figure 2.

| Transportation process | | Mass (kg) | Distance (km) | tons•km |
|---|---|---|---|---|
| Waste paper to cardboard mill | (T1) | 1518 | 150 | 227.7 |
| Cardboard to cutting plant | (T2) | 1315 | 550 | 723.2 |
| Packagings to consumers | (T3) | 1120 | 100 | 112.0 |
| Waste to incinerator | (T4) | 448 | 50 | 22.4 |
| Waste to dumping site | (T5) | 672 | 50 | 33.6 |
| | | | Total amount of tons•km: | 1118.9 |

Table 6.6 presents the environmental impacts connected with the transportation processes during the life cycle of both packagings. The information in Appendix A has been used for this table.

Table 6.6: Environmental impacts connected with the transportation processes during the life cycle of 10,000 packagings for potted plants.

| | | Packaging material | |
|---|---|---|---|
| Environmental impact | Unit | Recycled PET | Cardboard |
| Energy consumption | GJ | 0.62 | 2.85 |
| Emissions into air | | | |
| Aerosol | kg | 0.05 | 0.23 |
| CO | kg | 0.17 | 0.77 |
| $CO_2$ | tons | 0.04 | 0.21 |
| Hydrocarbons | kg | 0.11 | 0.49 |
| $NO_x$, as $NO_2$ | kg | 0.67 | 3.07 |
| $SO_2$ | kg | 0.05 | 0.22 |

## 6.4 Environmental impacts during waste treatment

After use, the packagings are disposed of as domestic waste. This means that 60% will be dumped and 40% will be incinerated (Netherlands situation, 1990). Both methods are connected with environmental impacts. In the case of landfill, only space occupancy is relevant for both materials. The measure of space occupancy can be determined by multiplying the volume of the dumped materials by a factor indicating the compressibility of the materials. For instance, the specific mass of PET is 1370 kg/$m^3$, the volume of 240 kg of PET amounts to 0.175 $m^3$. However, the dumped plastic material cannot be compressed in such a way that no space remains in between the material. This is why the volume is corrected by a factor that may differ between materials. For PET this factor is fixed at 1.10 (6), bringing the space occupancy of 240 kg dumped PET to 0.193 $m^3$. For cardboard this factor is fixed at 1.00. The specific mass of the cardboard in question is 777 kg/$m^3$. If 60% of the cardboard packagings (with a total mass of 1120 kg) is dumped, the space occupancy will amount to 0.865 $m^3$.
In the case of combustion, emissions into air occur. When calculating the emissions during combustion of the packagings, information from Emission Registration can be used, collected by the TNO Institute of Environmental Sciences, under the direction of the Dutch Ministry of Housing, Physical Planning and Environment. The emissions have been allocated to the packagings on a mass basis, as it is impossible to allocate each single component in the flue gas of an incinerator to the separate components of the incinerated waste. However, some emissions of the waste incinerator certainly do not originate from the materials under study. In this respect, compounds such as hydrogen chloride and hydrogen fluoride may be mentioned. Consequently, such emissions are not considered here.
Some energy may be regained during waste incineration. In some European countries, the municipal waste incinerators are well-equipped for this purpose and high efficiencies can be achieved. In Sweden, for instance, where the regained energy is used for district heating, an efficiency of about 75% is reached (calculated with respect to the heat of combustion of the materials).

In the Netherlands, the released heat is almost exclusively used for electricity generation, which is returned to the public network. However, the losses that occur during this process are relatively large. As a consequence, the efficiency is low and amounts to about 25%.
The heat of combustion of cardboard is about 16 GJ/ton; in the case of incineration, about 4 GJ/ton may be regained. The heat of combustion of PET is about 27 GJ/ton; about 6.75 GJ/ton may be regained.

Table 6.7 presents the environmental impacts during waste treatment of 10,000 packagings for potted plants. The energy regain leads to a negative value for the energy consumption. The table has been set up using Appendix A.

Table 6.7: Environmental aspects of the waste treatment of 10,000 packagings for potted plants.

| | | Packaging material | |
|---|---|---|---|
| Environmental aspect | Unit | Recycled PET | Cardboard |
| Dumped waste | kg | 268 | 672 |
| Dumping volume | $m^3$ | 0.21 | 0.86 |
| Incinerated waste | kg | 160 | 448 |
| Energy consumption | GJ | -1.08 | -1.79 |
| Emissions into air | | | |
| Fly ash (aerosol) | kg | 0.04 | 0.13 |
| CO | kg | 0.08 | 0.22 |
| $CO_2$ | tons | 0.12 | 0.34 |
| Hydroc, aliphatic $C_2$-$C_{10}$ | kg | - | 0.01 |
| $NO_x$, as $NO_2$ | kg | 0.23 | 0.65 |
| $SO_2$ | kg | 0.12 | 0.34 |

## 6.5 Environmental impacts during the entire life cycle

A combination of Tables 6.3 (production), 6.6 (transportation), and 6.7 (waste treatment) yields the overall environmental impacts connected with the entire life cycle of the packagings under study. The results are given in Table 6.8.

Table 6.8: Environmental impacts during the entire life cycle of 10,000 packagings for potted plants.

| | | Packaging material | |
|---|---|---|---|
| Environmental impact | Unit | Recycled PET | Cardboard |
| Energy consumption | | | |
| Electrical | MWh | 0.47 | 0.84 |
| Thermal | GJ | 0.78 | 13.24 |
| Total (*) | GJ | 5.28 | 21.24 |
| Emissions into air | | | |
| Aerosol | kg | 0.18 | 0.73 |
| CO | kg | 0.41 | 1.33 |
| $CO_2$ | tons | 0.46 | 1.84 |
| Hydrocarbons | kg | 0.13 | 0.60 |
| $NO_x$, as $NO_2$ | kg | 1.74 | 7.25 |
| $SO_2$ | kg | 2.08 | 10.53 |
| Emissions into water | | | |
| BOD | kg | 0.04 | 0.62 |
| COD | kg | 0.17 | 1.62 |
| Solid substances | kg | 0.11 | 0.39 |
| Solid waste | | | |
| To reprocesser | kg | | 195 |
| Landfill | kg | 268 | 672 |
| Space occupancy | $m^3$ | 0.21 | 0.86 |

(*): For the determination of the total energy consumption, the electrical and thermal energy have been added. However, this required two conversions. In the first place, the electrical energy consumption was converted from the unit MWh to GJ. This meant a multiplication by a factor of 3.6 (1 MWh = 3.6 GJ). For instance, 0.47 MWh corresponds with 1.70 GJ.
In the second place, electricity is being generated with an efficiency of 37.8% (UCPTE 88 model). This means, for instance, that the generation of 1.70 GJ of electrical energy requires the input of 4.50 GJ of primary energy (see Appendix A, section 2).

# 7 DISCUSSION

## 7.1 Introduction

In this chapter, the results of this investigation will be discussed and the packagings under study will be compared in the field of environmental impacts. No attention will be paid to other aspects which may be of interest to consumers, such as cost price, convenience of use, and handling.

Firstly, for each of the packagings, the partitioning of the environmental impacts over the life cycle will be considered. For instance, it will be examined whether a certain impact (e.g. the energy consumption or $CO_2$ emission) occurs primarily in a single field of the life cycle or is equally spread over the separate fields. For a limited number of environmental impacts, a graphic presentation of this partitioning will be given. This issue may be important in case of optimization of the packaging in question: the field with the greatest impacts will be of paramount importance.

Subsequently, the packagings will be compared and will initially be conducted using Table 6.3 (production), 6.6 (transportation), 6.7 (waste treatment), and 6.8 (overall view). Besides, a graphic presentation will be given with a limited number of environmental impacts for both packagings.

Finally, it will be examined briefly whether there are possibilities for optimization in the life cycle of packagings for potted plants.

## 7.2 Environmental impacts of the individual packagings

### 7.2.1 Packagings made of recycled PET

The energy consumption during the life cycle primarily takes place in the production phase. This phase includes the reprocessing of disposed PET bottles into grains, the extrusion of film, the manufacture of packagings for potted plants, and the reprocessing of waste cuttings into film. Compared with the production phase, the energy consumption during the transportation processes is low. The total energy consumption during all

transportation processes amounts to about 11% of the energy consumption during the production phase.
During waste treatment, energy can be regained in the incinerator. In this way, about 17% of the originally supplied energy can be recovered. This aspect of waste treatment is currently receiving much attention. It is expected that, in the near future, a higher efficiency than the current figure of 25% will be achievable. Besides, in accordance with the National Environmental Policy Program, there is the aim of raising the share of incinerated and reprocessed waste and lowering the share of dumped waste. As a consequence, a larger part of the production energy may be recovered in the future.

For the four major emissions into air, a subdivision has been made into the separate phases in the life cycle of the packagings. Production, transportation, and waste treatment are distinguished in the following graph. No absolute values are given in this graph, but the values are plotted as the percentage of the total emission of the relevant component over the entire life cycle.

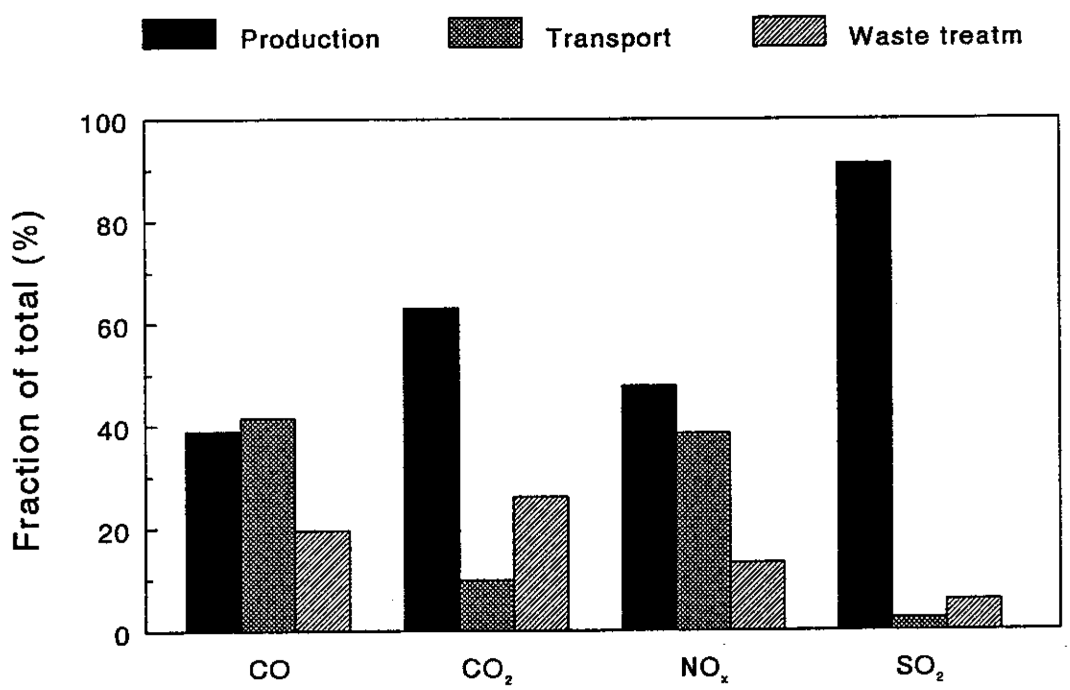


Figure 7.1: Some important emissions into air during the separate phases in the life cycle of the packagings made of recycled PET.

It appears from this figure that the emissions primarily occur during the production phase. The shares of transportation processes and waste treatment are clearly smaller. Nevertheless, the emissions are significant in these phases as well.

From the foregoing, it appears that the most important environmental impacts occur during the production phase. This holds for energy consumption, as well as for emissions.

### 7.2.2 Cardboard packagings

The energy consumption during the life cycle primarily takes place during the production processes, especially during the manufacture of cardboard from waste paper. Despite the fact that relatively major transportation processes occur in the life cycle of the cardboard packagings, the share of these transportation processes in the total energy consumption is still relatively small.
The energy consumption during all transportation processes amounts to about 14% of the energy consumption during the production phase.
For this type of packaging, there are also possibilities for energy regain during waste incineration. Under the present circumstances, about 8% of the originally supplied energy may be recovered. Naturally, also for the cardboard packagings, this aspect will play a more important role in the near future, when municipal waste incinerators will be better equipped for energy recovery and when a larger share of municipal waste will be incinerated.
For the four major emissions into air, a graphic presentation is given in which a subdivision has been made into the separate phases of the life cycle.

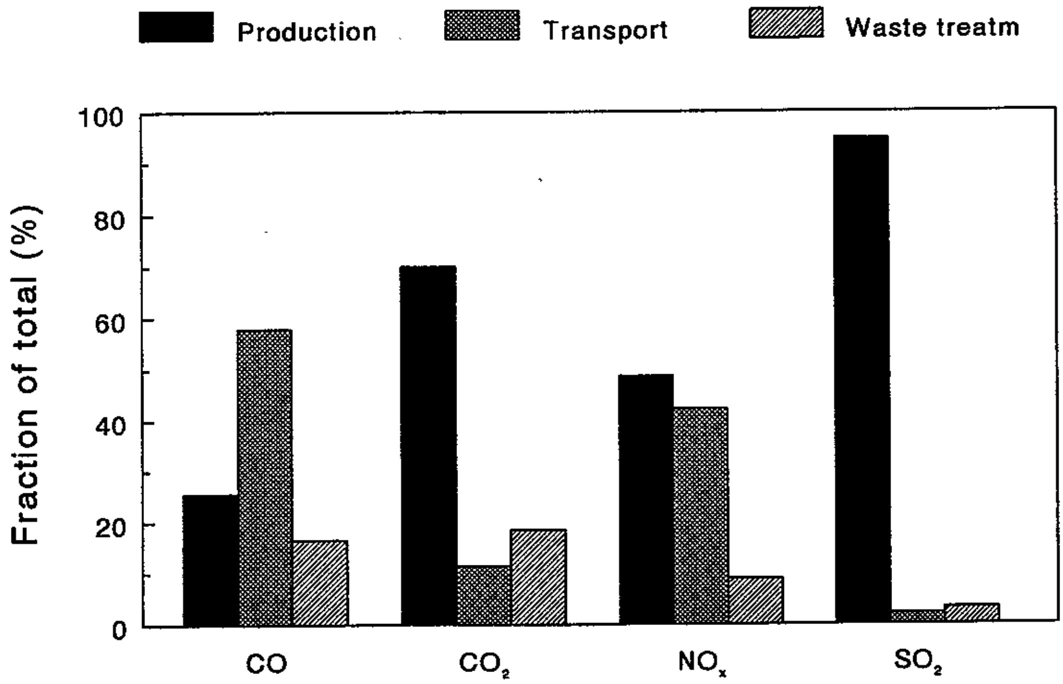


Figure 7.2: Some important emissions into air during the separate phases in the life cycle of the cardboard packagings.

The major emissions occur during the production processes. However, the other processes (especially the transportation processes) play an important role as well.
From the foregoing, it appears that the major environmental impacts for the cardboard packagings occur during the production processes. Cardboard production entails some particularly high-energy consumption processes. Although the emphasis lies in the production phase, the share of the transportation processes in energy consumption and emissions into air are certainly not negligible. For example, this is related to the fact that, on the one hand, relatively large masses have to be transported, while, on the other hand, de transportation distances are long.

In this investigation, it is assumed that the packagings are disposed of as municipal waste after use. However, when it is assumed that only 50% of the packagings is treated as municipal waste and the remainder enters the waste paper circuit, the overall environmental impact will be limited. While the packagings are being transported to the waste treatment plant and during waste treatment itself, the environmental

impacts will decrease. However, in this investigation, it appeared that these processes contribute significantly less to the overall impacts than the production processes.
The environmental impacts during transportation of the packagings will decrease by about 2.5% as only half of the original amount of packagings will have to be transported to the waste treatment plant, the total amount of tons•km will decrease from 1118.9 to 1090.9. The environmental impacts during waste treatment will be decreased by 50% because the amount of waste to be incinerated or dumped will be halved.
If the overall environmental burden of cardboard packagings is taken into consideration, the alternative waste scenario will have the following consequences:

- space occupancy after dumping will decrease by 50%;
- emissions into air will decrease by an average of 6.5%; depending on the component in question, this value will lie between 9.8% (CO) and 1.6% ($SO_2$);
- the total energy consumption will increase by about 3.9% (during incineration, less energy can be recovered).

## 7.3 Comparison of the two packagings

In Figure 7.3, a graph is presented in which the packagings under study are compared to each other with respect to some environmental impacts. In this case, the overall energy consumption, emissions of CO, $CO_2$, $NO_x$, and $SO_2$ into air, and space occupancy of solid waste are considered.
No absolute values are given in the graph. In each separate field, the larger of the two values is fixed at 100%; the other value is related to this larger value.

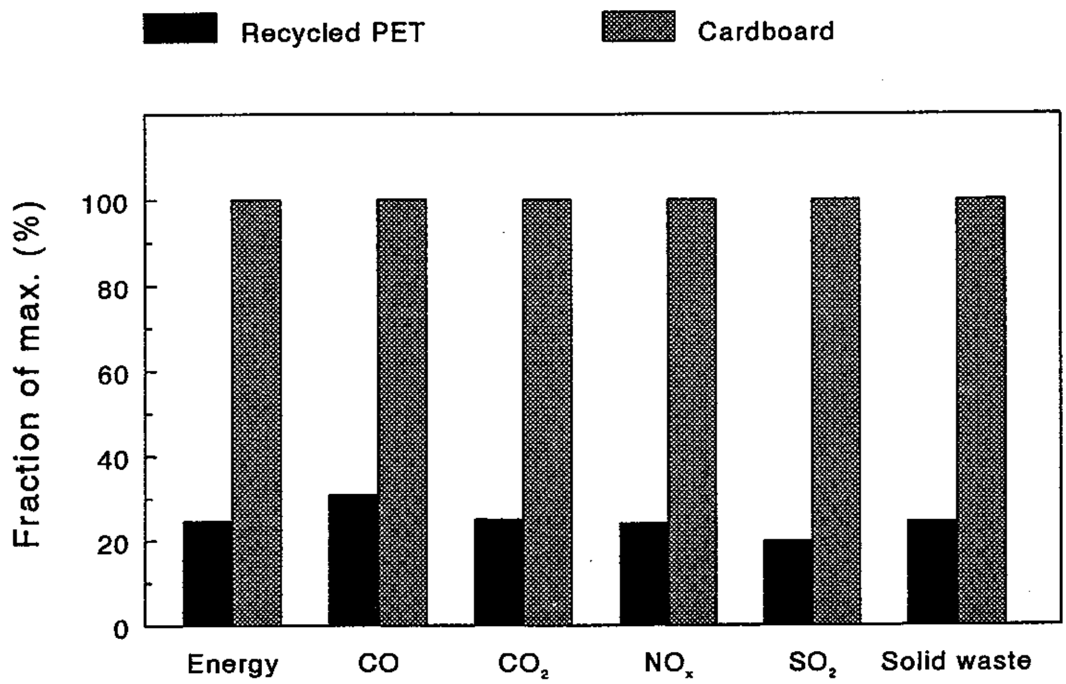


Figure 7.3: Comparison between the packagings for potted plants on some environmental impacts.

Figure 7.3 shows that the use of cardboard packagings is connected to larger environmental impacts on every single field. It is true that the graph does not give a complete overview of all relevant impacts, but for the remaining aspects (emissions of aerosol and hydrocarbons into air, emissions into water) the picture is similar: the use of cardboard packagings is accompanied by greater environmental impacts.
The difference between both packagings is about the same on each of the aspects that shown in the graph. The volume of the environmental impact connected with PET packagings ranges from 20 to 30% of the volume of the same impact connected with cardboard packagings. The same picture emerges for the impacts that are not given in the graph.

With respect to the space occupancy of solid waste it should be remarked that the values mentioned in this report refer to the situation immediately after dumping. While the materials are decomposing, the space occupancy will of course decrease. It is well-known that plastics decompose very slowly under normal circumstances. Only after some hundreds of years may any effect be expected. The decomposability of cardboard is better, but under the circumstances that are common on dumping sites (most of the waste is covered by other layers of waste), this decomposition proceeds slowly as well. At a rough estimate, only after some decades may any effect be perceptible in this case. Thus, with respect to the long-term space occupancy, there may be a slight advantage for cardboard packagings. It is to be expected, however, that this situation will change in the near future. In accordance with the National Environmental Policy Program, there is an aim towards more reuse of products and materials. Where this is not possible, it is preferable to incinerate the materials. By the end of this century, this should lead to a situation in which no more municipal waste is being dumped.

In the foregoing, it was assumed that the cardboard packagings would be treated as municipal waste after use. However, it was mentioned in section 4.2.2 that a situation in which half of the packagings would be recycled would be examined as well. According to section 7.2.2, this would only have a minor effect on the overall environmental impacts during the life cycle of the cardboard packagings. Considering the differences that emerge in this investigation, the examined shift in the waste treatment of cardboard packagings will have no consequences for the conclusions of this investigation.

This investigation started from the assumption that the potted plants would be mailed within the Netherlands. Should the sales take place in other countries, this will have consequences for transportation (longer distances) and waste treatment (foreign situation). If the transportation distances increase, the higher mass of the cardboard packagings will result in a greater increase of energy consumption and emissions than is the case for PET packagings. Thus, the already existing differences will increase further.
The replacement of the situation in the Netherlands concerning waste treatment by, for instance, an average European situation, will not likely have any significant consequences for the overall view. In the first place, the environmental impacts during waste treatment are low, compared to the impacts during production and transportation. Consequently, changes in waste treatment will not effect the overall

picture seriously. In the second place, the situation in the Netherlands already reflects the average European situation to a reasonable extent. In the Netherlands, 60% of municipal waste is dumped, the remaining 40% is incinerated. In other European countries, the percentage of incinerated waste varies from 0% (Ireland, Greece, and Portugal) to 75% (Luxembourg). In Germany this is 36%, whereas in France this is 42% (9). It is true that the emissions during incineration would increase in case of a shift to an average European situation, since in the Netherlands relatively severe conditions are imposed on the maximum allowable emissions during waste incineration. However, this increase in emissions during waste treatment holds for both packagings, so that the general conclusions of this investigation will not change in this respect.

## 7.4 Backgrounds of the differences in environmental impacts

The use of cardboard packagings is accompanied by significantly higher environmental impacts than the use of packagings made of recycled PET. This holds for energy consumption, emissions, and the amount of solid waste. The differences cannot be traced back to a certain part of the life cycle; the differences arise during production, as well as during transportation and waste treatment. The most important factor in this respect is the higher mass of the cardboard packagings: one cardboard packaging weighs 112 grams, against 40 grams for one PET packaging. Of course this difference will not only recur during production (more material has to be produced for cardboard packaging), but also during transportation and waste treatment.

Apart from that, some other aspects are of interest. Waste cuttings which have originated during the production of both packagings, are efficiently returned into the process chain for the PET packagings, but not for the cardboard packagings. The PET waste is brought to a reprocesser where it is made into film with a relatively low energy investment and can be directly used in the production of packagings. Despite the fact that the reprocesser is located at a relatively long distance from Voges (which means a long transportation distance), this method of material reuse implies a positive contribution. In this way, the manufacturer can save new material which has to be produced from waste bottles. It is true that the cardboard waste is brought to a reprocesser as well, but it is not returned into the process chain of the packagings for potted plants. To compensate for this material loss, more new material has to be produced, which entails extra energy investments and emissions into air and water. Another important factor is that the cardboard mill is located at a great distance from the packaging factory, involving long transportation distances which of course has its consequences for energy consumption and emissions.

## 7.5 Possibilities for optimization

This section will briefly deal with possibilities to introduce improvements (from an environmental point of view) in the life cycle of the packagings under study. The existing situation will be taken as the starting point.

In the first place, it is clear that improvements in waste treatment are possible for both packagings. At present, both packagings are disposed of as domestic waste after use, whereas it is technically possible to reprocess the material. The material of the packagings may be used for the production of plastic film (PET packagings) or cardboard sheets (cardboard packagings). However, practical implementation is not currently feasible for PET packagings. For cardboard packagings, a connection with the already existing collection circuit of waste paper could be made. Although reprocessing the cardboard packagings seems more feasible than reprocessing the PET packagings, these programs are not yet under discussion.

A second possibility for improvement, somewhat less radical than the first one, is a shift towards the incineration of waste, in combination with an intensified attention for energy regain during waste incineration. This leads to a decrease in space occupancy and to an increase in the amount of energy to be regained. It is true that this will also lead to an increase in the emissions into air (waste incineration), but incineration is generally considered a better solution than landfill, by the Netherlands government. In view of government policy in this field, it is reasonable to expect that this shift will take place in the near future. This will denote an improvement for both packagings.

Waste cuttings are produced during the manufacture of both packagings. The waste of the PET packagings is reused in the manufacture of packagings, after a short reprocessing procedure. From an environmental point of view, no improvements can be made to this procedure. Cardboard waste cuttings are not returned into the process chain, so that improvements may be possible here. However, there is no short reprocessing procedure for cardboard waste. The waste cuttings should be returned to the cardboard mill and should be introduced at the beginning of the cardboard manufacturing process. This means that no real improvements are possible here.

There are several transportation processes involved in the life cycle of the packagings. The extent of these processes can be limited by decreasing the transportation distances. Production processes should be conducted at locations that lie closer to each other than is currently the case. In the first place, it remains to be seen whether there are possibilities for such an improvement. In the second place, the output of such an intervention is probably limited, as the transportation processes only make a minor contribution to the overall environmental impacts.

In summary, at this moment, there are only limited possibilities to improve the packagings under study from an environmental point of view. It should be remarked that this investigation starts from the present state of the art and from the existing packagings. However, improvements in production processes and in the packagings themselves (e.g. decrease of their mass) are beyond the scope of this investigation.
There seem to be more possibilities for the optimization of cardboard packagings. In view of the differences between the packagings that became apparent in this investigation, it is unlikely that these improvements would have a serious influence on the conclusions of this investigation.

## 8 CONCLUSIONS

In this investigation, two packagings for potted plants have been compared in the field of environmental impacts. In this case, the functional unit was 'the packing of 30,000 medium-sized mail-order potted plants'. This functional unit can be accomplished, among others, by 10,000 packagings made of recycled PET manufactured by Voges, and by 10,000 cardboard packagings (no further indication available) manufactured by another producer. Both packagings are available on the market. The mass of the PET packaging amounts to 40 grams, the mass of the cardboard packaging is 112 grams.
This investigation made as complete an inventory as possible of the environmental impacts during the entire life cycle (from base material production to waste treatment), after which the environmental aspects of both packagings were compared. The following points came forward:

- For the manufacture of both packagings, recycled materials are used. Both base materials (used bottles and packaging waste for the PET packagings and waste paper for the cardboard packagings) originate from an existing collection program. In both cases, no 'new' raw materials are used. The PET packagings require 428 kg of base material; for the cardboard packagings, this is 1518 kg;
- For both packagings, the environmental impacts primarily occur during the production processes. The transportation and waste treatment processes contribute significantly less to the overall environmental impacts;
- The environmental impacts during the production processes primarily originate from the generation of energy;
- When comparing the environmental impacts during the entire life cycle of both packagings, the cardboard packaging appears to be connected with the greatest impacts on each relevant aspect (energy consumption, emissions into air and water, mass and space occupancy of solid waste). In some major fields, the environmental impact connected with the PET packaging ranges from 20 to 30% of the same impact connected with the cardboard packaging;
- The greatest impacts of the cardboard packagings occur in each of the separate fields: production processes (including energy production),

transportation and waste treatment. The main reason for these differences is the higher mass of the cardboard packagings;
- For both packagings, some of the consumed energy can be regained during waste incineration. The possibilities for energy regain are currently limited in the Netherlands municipal waste incinerators, but in the future this aspect will probably receive more attention. Besides, a shift will take place from landfill towards incineration. For both packagings, this will lead to a decrease in the net energy consumption and to a decrease in the space occupancy of solid waste. Apart from this improvement, there seem to be limited possibilities for further optimization in the near future;
- This investigation started from the assumption that the packagings are mailed within the Netherlands and that the packagings would be disposed of as domestic waste. However, it is possible that cardboard packagings are recycled after use. A short investigation was made on the influence of changes in the situation with regard to the waste treatment of cardboard packagings and to the locations to which the packagings are sent. In both cases, the conclusions of this investigation would not change significantly.

Of course, the above conclusions refer to the two packagings under study. These packagings are suitable for medium-sized potted plants. However, there is no reason to assume that for differently sized packagings the results of this investigation would deviate significantly. For packagings with other dimensions, the higher mass of the cardboard packagings would also lead to higher environmental impacts than would be the case for the corresponding PET packaging.
From an environmental point of view, the cardboard packaging could only compete with the recycled PET packaging if the mass of this cardboard packaging would be reduced significantly. However, the question whether this is practically attainable is not under discussion in this investigation.

On the basis of the results of this investigation, the conclusion can be drawn that, from an environmental point of view, packagings made of recycled PET are preferable to cardboard packagings. Consequently, under the present circumstances, the switch from packagings made of recycled PET to cardboard packagings for potted plants would not result in an improvement with respect to the environmental impacts.

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# Appendix A Environmental impacts during some base processes

## 1 Introduction

In this investigation, some processes have been discussed that are accompanied by certain environmental impacts. In this respect, processes are meant which are conducted during production, transportation, energy generation, and waste treatment. Some of these processes are more or less specific to this investigation, especially the production processes. Some other processes recur several times, not only within this investigation, but also within other investigations. This involves some transportation, energy generation, and waste treatment processes. For these cases, tables have been drafted which reflect the environmental impacts during these processes; these tables refer to a standard unit. When such a base process comes up for discussion, the table in question may be consulted. Usually a simple calculation suffices to make a conversion from the standard unit to the unit in question.
This appendix presents the environmental impacts during the following processes:

- the generation of 1 kWh of electrical energy (1 kWh = 3.6 MJ) according to the UCPTE 88 model;
- the generation of process steam per GJ of supplied energy, using heavy fuel oil as the primary energy carrier;
- the transportation of 1 ton of commodities over a distance of 1 km by a heavy lorry;
- the combustion of 1 ton of municipal waste in a municipal waste incinerator (situation in the Netherlands).

## 2 Environmental impacts during electricity generation

In this report, the UCPTE 88 model is used in the calculations on the emissions during electricity generation. This model is considered the most representative model of electricity generation in Western Europe. The formulation of this model started from the average situation in 1988 in the participating countries (including the Netherlands and Germany). According to this model, electricity is generated by the combustion of coal (16.6%), lignite (9.0%), fuel oil (9.3%), natural gas (8.0%), and by nuclear processes (36.9%) and water power (20.2%). Table A-1 gives the emissions into air that occur during the electricity generation according to this model. The table indicates how many grams of a certain compound are being emitted per kw of produced energy.

Table A-1: Emissions into air (per unit of produced energy) during electricity generation according to UCPTE 88.

| Emitted compound | Emission (g/kWh) |
|---|---|
| Aerosol | 0.128 |
| CO | 0.321 |
| $CO_2$ | 407 |
| Hydrocarbons | 0.009 |
| $NO_x$, as $NO_2$ | 1.230 |
| $SO_2$ | 2.312 |

N.B.: The efficiency of the electricity generation according to this model amounts to 37.8%. This means that for the generation of 1 kw or 3.6 MJ electric energy 9.52 MJ of primary energy is required.

## 3 Environmental impacts during the production of process steam

Emissions into air occur during the production of steam in industrial furnace installations which depend on the primary energy carrier(s). Table A-2 gives the emissions per GJ of supplied energy that occur when steam is being produced by the combustion of heavy fuel oil.

Table A-2: Emissions into air during the production of steam, using heavy fuel as the primary energy carrier.

| Emitted compound | Emission (kg/GJ) |
|---|---|
| Aerosol | 0.022 |
| CO | 0.006 |
| $CO_2$ | 78 |
| Hydrocarbons | 0.008 |
| $NO_x$, as $NO_2$ | 0.205 |
| $SO_2$ | 0.659 |

## 4 Environmental impacts during transportation processes

The calculations of the environmental impacts during transportation with heavy lorries (vehicles with a mass of more than 3500 kg when loaded) start from the assumption that the average load of these vehicles is 50%. This is derived from figures indicating that 70% of the full load capacity is utilized on loaded trips and that 30% of all trips are empty trips. The average full load capacity is about 9.5 tons.
On the basis of information from the Central Bureau for Statistics, a table has been drafted which indicates the environmental impacts during transportation (by heavy lorries) of 1 ton of commodities over a distance of 1 km. The table is given below.

Table A-3: Environmental impacts per ton•km during transportation of commodities by heavy lorries.

| | |
|---|---|
| Energy consumption (MJ) | 2.55 |
| Emissions into air (g) | |
| Aerosol | 0.21 |
| CO | 0.69 |
| $CO_2$ | 185 |
| Hydrocarbons | 0.44 |
| $NO_x$, as $NO_2$ | 2.74 |
| $SO_2$ | 0.20 |

## 5 Environmental impacts during the incineration of municipal waste

Emissions into air occur during the incineration of municipal waste. The TNO Group on Emission Registration has been collecting emission data on a large number of industrial processes in the Netherlands since the seventies. This process takes place under the direction of the Dutch Ministry of Housing, Physical Planning and Environment.
One of the processes under study is the incineration of municipal waste in municipal waste incinerators. Table A-4 gives the emissions into air that occur during the combustion of 1 ton of municipal waste.

Table A-4: Emissions into air during incineration of 1 ton of municipal waste.

| Emitted compound | Emission (kg) |
|---|---|
| Fly ash | 0.28 |
| CO | 0.48 |
| $CO_2$ | 771 |
| Hydrocarbons, aliphatic $C_2$-$C_{10}$ | 0.03 |
| $NO_x$, as $NO_2$ | 1.44 |
| $SO_2$ | 0.76 |