MATERIAL EFFICIENCY IMPROVEMENT FOR EUROPEAN PACKAGING IN THE PERIOD 2000 - 2020

MARKO HEKKERT, LOUIS JOOSTEN AND ERNST WORRELL

Utrecht University, Department of Science, Technology and Society, Padualaan 14, NL-3584 CH Utrecht, The Netherlands

Abstract-In this paper the current material consumption for packaging making in Europe is described. Per packaging type (food bottles, non-food bottles, boxes for primary packaging, flexible packaging, carrier bags, industrial boxes and pallets) options for improved material efficiency are described. The options are in the field of using thinner materials, using less material by changing the shape of the package, using recycled material and using refillable packages. This paper shows that many option are available to reduce the future material input for packaging and that a reduction of CO_2 emissions by this sector with a factor 2 is possible. A substantial share of this reduction can be achieved without any changes in consumer behavior.

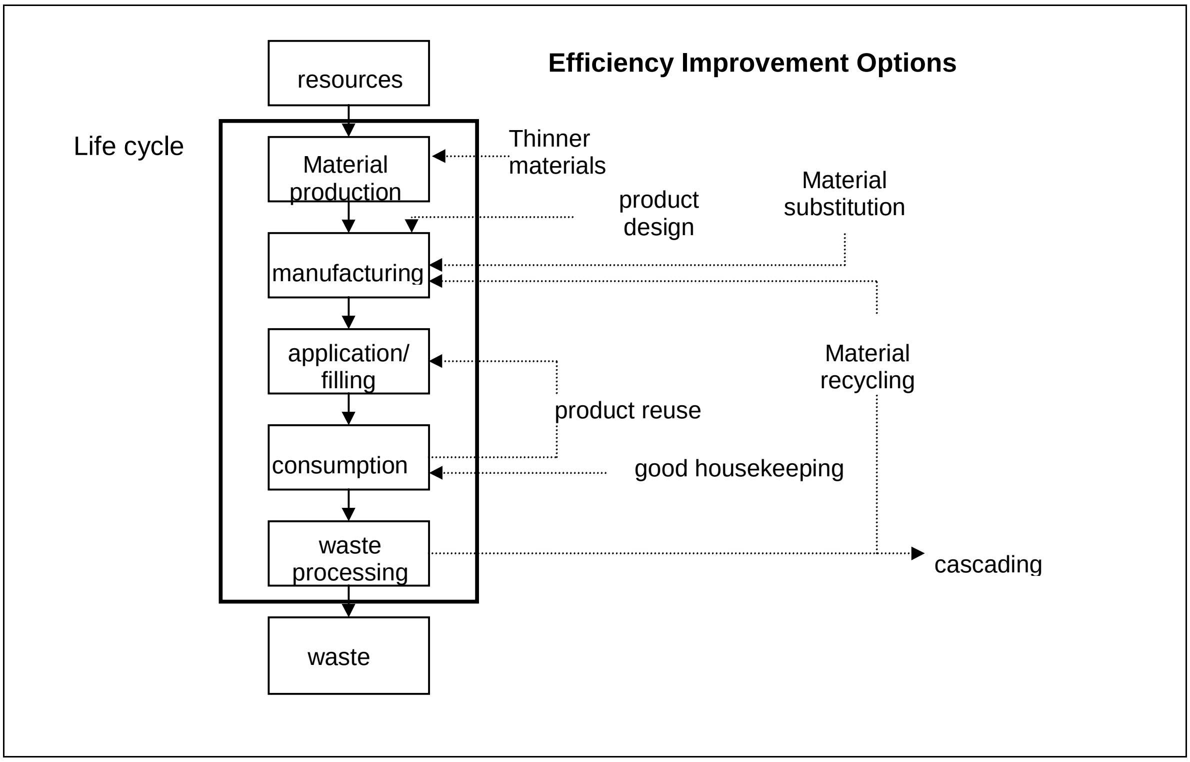
1. Introduction

Packaging is an important product category from a CO_2 point of view. In Table 1.1 a first order estimate for the energy and CO_2 balance for packaging materials are stated. The total direct and indirect CO_2 emission of 109 Mtonne for all packaging materials can be compared to the current Western European emission of approximately 3300 Mtonne [Gielen, 1997]. The packaging materials that are analyzed in this report represent 3.3 percent of the total Western European CO_2 emission or about 10% of European industrial CO_2 emissions. Plastics, paper and metal are the most important contributors to the CO_2 emissions from packaging.

This paper describes possible material efficiency options by the packaging industry and the material processing industry that may lead to reduced CO_2 emissions in Europe. Material efficiency is defined in this paper as the amount of primary material that is needed to fulfill a specific function. Material efficiency improvement allows the same function to be fulfilled with less material. At several stages in the life cycle intervention is possible in order to increase the material efficiency over life cycle. Figure 1.1 shows these efficiency improvement measures and at which stages in the life cycle they intervene. The standard life-cycle is presented within the box. The efficiency improvement measures that can be applied are depicted outside the box.

Even though in this paper we focus on efficiency improvement of packaging materials we need to take into account that packaging is needed for the protection and marketing of the packaged products. In many cases this paper states the technical possibilities but before actual implementation a good understanding of the purpose of packaging material is needed. Savings on packaging material may in some cases lead to less efficient product use which may even lead to greater consumption of energy per consumption unit than the original situation. However, arguments like these should not prevent that resources are used in the most efficient way possible. This paper investigates which packaging options are suitable to reach an efficiency improvement with a factor 2 in 2020 and also if a factor 10 is possible on the long run (2050).

Figure 1.1. The life-cycle of materials, adapted from Worrell *et al*., (1995).



In order to model possible changes in material consumption we discerned 7 packaging categories: food bottles, non-food bottles, boxes for primary packaging, flexible packaging, carrier bags, industrial boxes and pallets. For these categories we studied the present material input and the possible material options.

In this paper we will first describe the material efficiency improvement options for the different packaging categories. Next we will describe how we calculated the costs and the effect on CO2 emissions for the material efficiency options. Finally we will present the CO2 emissions and costs for all material efficiency improvement options. These calculations are first order estimates. More precise calculations require detailed insight in the material production processes of the packaging materials. This will be done by means of a MARKAL model that focuses on CO2 emissions reductions that are related to the Western European materials system. The options described in this paper will be use in this model as input data. The first order estimates are given in order to give insight in the question: is it possible to reduce CO2 emissions related to the use of packaging by a factor 2 or a factor 10 by means of material efficiency improvement.

To give an idea about which packaging materials are used for which products, Table 1.2 states the material input of packaging material per demand category.

Table 1.1: First order estimate of energy and CO_2 balance of packaging in Europe based on van Heijningen (1992), van Heijningen (1992a), APME (1996), de Beer *et al.*, (1994) and van Duin (1997)[1,2]

Consumption of Packaging materials	Consumption (Mtonne/yr)	CO_2 (Mtonne/yr)	Share in total CO_2 emission (%)
Paper	28	14	13 - 17
Glass	17	6	6 - 7
Plastics	12	23 - 61	28 - 56
Metal	6	15	14 - 18
Others (incl. Wood)	13	13	11 - 12
Total	75	84 - 109	100

Table 1.2: Material input per packaging service category

demand category	material input (ktonnes)	material type	demand category	material Input (ktonnes)	Material Type
beverages, carbonated	252	Steel	**non-food**	798	Cardboard
	171	Aluminum		672	PVC
	1131	PET		260	PE
	15605	Glass		140	PP
	199	PE		10	Paper
	745	Board			
	447	PS	**carrier bags**	430	PE
	73	PP			
			industrial bags	600	PE
wet food	800	Glass		504	Paper
	188	Steel		400	PP
non-food liquids	1050	PE	**transport Packaging**	2610	PE
				259	Wood
dry food	2577	Cardboard		9400	Corrugated board
	224	PVC			
	840	PE	**Pallets**	4956	Wood
	1530	PP		840	PE
	47	Paper			
	110	PET			

1 The CO_2-emission is calculated by using the figures in Annex 3 of van Duin (1997). The CO_2 emission of metal is calculated by assuming a 4:1 ratio of steel and aluminum and an European average of recycling.

2 The ranges in table 1.1 are the result of the feedstock related CO_2 emissions of plastics. No energy recovery of plastics has been taken into account.

2. Material efficiency options for different packaging categories

2.1 Food bottles

The category food bottles is defined as all bottles, cans and jars that are used to pack food. A very large category is liquid packaging. The main liquid types that are packed within this category are dairy products, soft drinks, beer, wine and spirits. The total European consumption of these products amounted to 111 billion liters [EC, 1997]. Also preserved fruit and vegetables are important in this category, 4 billion liters in 1994 [EC, 1997]. Current most used materials to pack the products in this category are glass, PET, liquid board, steel and aluminum

glass

Glass bottles and jars are used to pack all of the liquid and food categories that are defined earlier. The glass bottles have had competition from other materials since a long time. Years ago, milk in The Netherlands was sold in glass bottles but today the major packaging used are liquid cartons [van der Ent, 1995]. In the soft-drink sector, a similar situation occurred. For a long time only glass was used while today PET bottles have taken a very large market share in Europe. Still, glass has a large market share in the packaging used in Europe. About 23% of the packaging materials is glass which corresponds to 17250 ktonne in 1994 [APME, 1996]. In 1995 54% of glass packaging in Europe was collected for recycling [Anon. 1996].

For the MARKAL- model we will define 2 glass bottles (large and small) and 1 jar. The large bottle is defined as a bottle with a volume of 1 liter while the small bottle has a volume of 0.3 liter. The jar has a volume of 0.5 liter (in between the often used standards of 72 and 37 centiliter). Based on SVM (1993a) we estimate the weight of these bottles and jars at 500, 250 and 250 grams respectively.

The glass bottles can be improved in order to reduce the amount of packaging waste. In the Netherlands many projects have taken place to reduce the weight of glass bottles. The weight of milk bottles was reduced with 33%, the weight of several liquor bottles was reduced with 20% and 22% [SVM, 1994]. It seems possible to reduce the weight of large glass bottles in Europe with 25% in 2020. Projects have taken place to reduce the weight of small glass bottles like beer bottles with 5.5% [SVM, 1994]. The glass industry in The Netherlands expected in 1993 a weight reduction of 15% in 1995 compared to 1991. We will use this figure for the improvement of the small glass bottle [SVM, 1993]. The weight of mushroom jars was reduced with 20% by a company in 1994 and in 1992 vegetable jars were reduced in weight with 14%. Furthermore, some jam and jelly bottles were reduced in weight by 10% in 1995 [SVM, 1992, 1994, 1995].

Besides weight reduction a lot of resources can be saved by glass recycling. Two types of recycling are possible: product re-use and material recycling. Currently, the European recycling rate is already 50%. The Swiss recycling rate is the highest in Europe (85%) and can be seen as the absolute maximum for Europe. However, due to the large transportation distances in Europe in rural area’s this figure is not very likely to be reached. We assume a maximum recycling rate in Europe of 70%. We furthermore assume that color separation is possible for all the glass that is collected separately; in the U.K. already 95% of the recycled glass is sorted on color. In The Netherlands beer bottles and some jar types are recycled with a deposit system (product recycling). We assume that this system is also an option for Europe after 2000. . The success of such a system depends on the willingness of the consumers to return the package (this can be influenced by the height of the deposit fee) and the willingness of the producers to implement such a system. Standardization of packaging is a strong tool to make product recycling work. In this way it doesn't matter if the package is returned to producer A or producer B. Standardization for beer bottles is proven technology in The Netherlands. We will therefore only use this option for beer bottles in Europe. We assume a trip number of 20 trips per bottle

PET bottles

PET (Poly Ethylene Terephthalate) bottles were introduced in the soft drink sector to replace the standard 1 liter glass bottles. PET bottles are especially suited to pack carbonated soft drinks. PET bottles also replace PVC bottles that are often used in South Europe for the packaging of mineral water [Ent, 1995]. 50% of the PET packaging in Europe are used to pack soft drinks, 27% is used to pack mineral water, and 5% is used to pack other drinking liquids. The rest (18%) is used for other purposes like food and non food packaging [Clausse and Mitchell, 1996].

In 1993 about 700 ktonne PET for bottles was used in Europe and projections for 2000 and 2005 suggest a demand for PET of 1.55 million tonne and 2.12 million tonnes respectively [Anon., 1995, Clausse and Mitchell, 1996]. These trends are based on expectations that PET bottles will replace all PVC and a lot of glass packaging.

Most PET bottles used in Europe are one way PET bottles. We will model these bottles as having a volume of 1.5 liter and a weight of 50 grams. In The Netherlands and germany many PET bottles used are refillable. This development was possible because new PET types became available that could be cleaned at higher temperatures (58°C). In 1994 Spadel introduced the Hotwash Pet bottle that can even be cleaned at temperatures up to 75°C [Hentzepeter, 1996]. The refillable PET bottles (REF-PET) are designed to make 25 trips during a lifetime of 4 years [Kort, 1996]. Many bottles, however, make less trips because of the damage done to the bottles during the refill process (scuffing). We will model the refillable PET bottle as having a volume of 1.5 liter, a weight of 103 grams and a trip number of 20.

PET bottles normally are made out of virgin PET but the three layer PET bottle with a recycled PET inner layer can be seen as an improvement option. We will use the bottle with 25% recycled PET as improvement option for the virgin bottle.

Liquid board

Cartonboard has been used to pack liquids for a long time. The Tetra Classic was introduced as early as in 1952 [PPI, 1996]. The most important markets for liquid cartonboard are milk and juice packaging. Less important are wine, water, and soup packaging [PPI, 1996].

In order to hold liquids liquid board is laminated with other materials like PE and aluminum. Tetra Briks for juice packaging for example contain 75% cardboard, 20% PE and 5% aluminum and the total weight is 28 grams for a 1 liter package [Buelens, 1997]. Cardboard is used as middle layer with a PE and aluminum layer on the inside and a PE outer layer. The liquid board package is not expected to undergo radical changes in future years. To keep up the competition strength more plastics may be used for easier openings and better closures. Material savings are reported by increasing the size of the 1 liter package to 1.5 liter. This saved 9% packaging material per liter [SVM, 1994].

Metal packaging

In 1995 around 4 million tonnes of packaging steel was used in Europe. Furthermore another 3.1 million tonnes of aluminum was used. For the beverage market 14.3 billion steel cans were used in 1995. The consumption of aluminum cans in the beverage sector was even larger (17.5 billion cans) [Depijpere, 1996].

In Europe there is a strong competition between steel and aluminum for beverage cans. Almost all lids of European beverage cans are made out of aluminum while 50% of the bodies of the cans are made out of steel and another 50% out of aluminum [Depijpere, 1996]. In contrast in the U.S. almost all cans that are used in the beverage industry are made out of aluminum (95%) [Meert, 1995]. For food cans the situation in Europe is entirely different. Tin-plated steel commands 100 percent of the food can market [Abbott, 1995]. The size of the "steel" food market is estimated at 2000 ktonnes [Meert, 1995, Depijpere, 1996].

Many developments have been going on in the last decades to reduce the weight of steel beverage cans in order to save materials costs. In the last decade the weight of steel beverage cans have been reduced by 20% [Depijpere, 1996]. The current body of a steel 33 ml can weighs about 27 grams. It is already possible to produce a steel can that weighs 23 grams. Hoogovens is working on ultra thin steel that should make it possible to produce cans that weigh 18 grams in 2000 [van der Ent, 1995, Depijpere, 1996, van Deijck, 1994].

A new development in the steel can business is the introduction of the all steel can. The can is developed by Hoogovens, British Steel and Rasselstein. The difference with the normal steel beverage can is the steel 'push in' lid. The advantage of the all steel can is that the can be recycled entirely. Aluminum that normally is part of the can, can not be recycled because it is incinerated in the recycling process [van Deijck, 1994]. The lid of the all steel can weighs about 8 grams. The total weight of the all steel can in 2000 will be around 26 grams.

The developments in aluminum beverage cans are very similar to the developments in steel cans. Producers have also been working on reducing the weight of the cans. The current body of an aluminum can weighs around 11.5 grams. The current lid weighs another 2.7 grams which leads to a total can weight of around 14 grams [Depijpere, 1996, van der Ent, 1995]. Alcan, a large aluminum producer, estimates that an aluminum can in 2000 can weigh 13 grams (including lid) [Goddard, 1994].

Besides developments in the beverage sector also food cans are made lighter. A liter can weighs around 88 grams in stead of 115 grams in 1985 (savings of 35%) [van Stijn, 1996]. Continental Can is currently working on a 'honeycomb can'. This can has a honeycomb structure which makes the can stronger. This structure makes it possible to produce a can that weighs 30% less [van Stijn, 1996]. We expect the market penetration to be lower then 100% because labels can not be attached as easily and the printability is worse than for normal cans.

PS and PP cups

Cups made from thermoformed plastics are used for packing of yogurt and butter. Popular materials are PS, PP and PVC with market shares of respectively 52, 15 and 25% [APME, 1996]. We will model two cups. One is made from PS and has a weight of 14 grams and capable of packing 500 gram product. The other cup is made from PP and weighs 12 gram [Phylipsen, 1993].

PE pouch and PC bottle

Both Tetra Pak and Elopak have introduced flexible packaging (pouches) for milk and juice. The pouches are made out of plastic. Tetrapak uses LLDPE and Elopak uses multiple layer PP laminates [Couwenhoven, 1996]. The advantage of using pouches for liquid packaging is that they are extremely light. An empty 1 liter pouch from Elopack weighs 10 grams while an empty 1 liter pouch from Tetra Pak only weighs 4 grams. We will model the Tetra Pack pouch as improvement option for current packaging options. It needs to be taken into account that this option asks for a change in consumer behavior because a pouch does not have the same packaging characteristics as non-flexible packaging.

In the Netherlands the PC bottle is introduced as an alternative for liquid board milk packaging. We will model this bottle (trip number of 30 and a weight of 80 grams for a liter bottle) as alternative for current packaging types for non carbonated drinks.

2.2 Non-food bottles

Non-food bottles are used to pack shampoos, detergents and other cleaning liquids, lubricants, and light cleaning chemicals. Contrary to food bottles not as many different materials are used to pack the liquids. The food sector puts high demands on the quality of the material because properties like CO_2 and oxygen permeability are very important for the durability and quality of the packed product. In the non-food sector these factors are less important.

The main material used to produce non-food bottles is HDPE. We estimate the amount of non-food bottles on the HDPE blow moulding data for Europe. In 1994 about 1125 ktonne HDPE bottles were used in Europe [APME, 1996]. Besides non-food bottles also the U.K. milk bottles are made out of HDPE. This leaves 1050 ktonne HDPE for non-food bottles.

For the Markal model we define a non-food bottle with a volume of 0.5 liter and a weight of 50 grams. Several improvement options can be modeled. Based on SVM (1992-1996) we estimate that it is possible to reduce the weight with 25%. Furthermore bottles can be made with a recycled HDPE content of 50% [SVM, 1994]. Two other options are more difficult to implement: a refill package made out of cardboard (14 grams) and a plastic pouch (5 grams).

2.3 Boxes for primary packaging

The category 'boxes (primary packaging)' consists of all the non-flexible packaging that is used as primary packaging to pack food and non-food products. To estimate the amount of boxes used as primary packaging in Europe we make use of statistics on the materials that are used to make the boxes. In PPI (1997) the total amount of packaging board consumption in Western Europe is estimated at 4.8 Mtonnes. Subtracting the share for liquid packaging (745 ktonne) leaves 4 Mtonnes of board.

Besides cardboard, also plastic is a popular material for the production of boxes. In general plastic boxes have very thin walls and are not very durable. We estimate that the majority of these boxes are made out of thermoformed sheets. In Europe the amount of thermoformed sheets that are used as packaging is 1220 ktonnes in 1994 [APME, 1996].

To model the category boxes we will define two basic types of boxes: the cardboard box and the plastic box. We will also model a cardboard box with an inner bag. The standard cardboard box has a volume of 1 liter and weighs 35 grams. The inner bag will add another 3.0 grams (PE) or 7 grams (paper). A market share of 20% of the cardboard box market is assumed for the box with the inner bag. The plastic box will contain some cardboard in order to simulate the share of blister packaging. We will define a plastic box with a volume of 0.5 liter that contains 10 grams of plastics (HDPE) and 2 grams of cardboard.

Three improvement options are defined. The first deals with the use of smaller boxes, removal of trays, increasing product quantity, refill packages and use of thinner material. This is modeled by lighter boxes (28 grams). The second option replaces the inner bag by sealing of the box. The third improvement replaces the plastic blister with a cardboard blister (17.5 grams) as done intensively in the DIY sector [SVM 1992-1996].

2.4 Flexible packaging

From a materials point of view this group of packaging materials basically consists of three subgroups: plastic films, paper wrappings and aluminum films. Plastic films can be further broken down into different types of monolayer films and laminates. The total European market for flexible packaging amounts to some 5.2 million tonnes, of which PE films are estimated at 4.2 million tonnes and PP film at 0.8 million tonnes [APME, 1996].

Possible material changes in flexible packaging depends heavily on the products that are packed. For many food products barrier properties for moisture and gasses, especially oxygen and carbon dioxide, play a crucial role. Other products do not need high barrier properties. For this reason we modeled high and low barrier films.

In case of low barrier food films we modeled 1 liter bags out of LDPE (3.7 gram) and PP (2.7 gram). Substitution between the films can already improve material efficiency but specific improvement options are metallocene films which are about 20% thinner (2.2 grams) due to improved polymerization control in the production process [Anon. 1995, 1996, v. Stijn, 1996, 1997] and the use of paper wrappings (8 grams). In case of high barrier films several laminates are modeled which consist of two or more layers of different materials. Laminates either consist of two or more different plastics, or of a plastic with another material (e.g. aluminum or paper). We modeled PP, PET and metallocene laminated with PVdC (a super thin coating with excellent barrier properties) and the same plastics with a coating of aluminum.

Flexible packaging can also be used to pack non-food packaging and industrial packages. For non-food packaging we used the same films as for low barrier food packaging. For industrial packaging typical films are stretch films and shrink covers. These are used to bundle several packages together and often fix these bundles to pallets. Shrink covers are assumed to be 140 μm thick and a reduction to 100 μm is assumed to be possible [Zoethout, 1997]. Stretch films are assumed to be 30 μm thick but multiple turns around a pallet are necessary. Shrink films can in some cases also replace corrugated boxes. For shrink films we used an average thickness of 50 μm and a possible reduction in thickness of 10% [SVM, 1994, Plasthill, 1997, Zoethout, 1997].

2.5 Carrier bags

Carrier bags are most often made out of plastics, more specifically PE. Both LDPE and HDPE are used for the production. HDPE bags are normally lighter than LDPE bags [SVM, 1992].

Many different kinds of carrier bags are used in Europe which depends on the specific function of the bag. The thickness varies between 10 to 200 μm [Donker, 1993].

Several initiatives have been taking place in order to reduce the amount of plastics used for plastic bags. Many projects focussed on prevention. In the Netherlands this resulted in agreements in 1991 between the government and stores that plastic bags will not be handed out for free [CV, 1992]. These measures resulted in a reduction of the amount of carrier bags because consumers started to reuse bags or make use of durable carrier bags. Other initiatives focussed on alternative materials for carrier bags like paper.

We estimate the amount of carrier bags in Europe in 2000 at 430 ktonnes based on a European consumption in 1990 of 370 ktonnes which is linearly extrapolated with the estimated developments of PE in that period [APME, 1992, APME, 1994, APME, 1996]. Furthermore we assume an average weight per bag of 20 grams [Donker, 1993]. This results in a European demand for carrier bags of 21.5 billion bags per year.

Improvement options for the normal carrier bag are a bag that consists of recycled PE, a lighter PE bag (15 grams), a paper bag (56 grams) and a multiple use PE bag which weighs 240 grams but can be reused 100 times [SVM, 1993, Donker, 1993].

2.6 Industrial bags

Industrial sacks are used to pack plastics granulate, cement, animal feed, fertilizers, flour, soda, gypsum, compost etc. In APME (1992) the total use of plastic industrial bags is estimated at 460 kton. We will use this figure as an estimate for the amount of plastic industrial bags in 2000. The total plastic industrial bag consumption is estimated at 4.4 billion bags considering an average weight of 105 grams per bag with a carrying capacity of 25 kg [calculations based on: Bührmann-Vromen, 1997, Zoethout, 1997].

Besides plastic bags also paper bags are used. We will make an estimate for the amount of paper bags based on the amount of cement that is consumed in Europe (10% is carried in bags). Cement bags are made out of multiple layers of paper because of the bag needs to be very strong. The sacks have a standard carrying capacity of 50 kg which equals 25 liters in the case of cement. Today a clear trend is visible towards smaller bags because they are easier to handle [Ayoup, 1997]. The amount of paper bags is calculated at 340 million bags (assuming bags of 50 kg). The paper bag is modeled as a bag that weighs 262 of which 10 grams PE.

A possible improvement option for industrial bags is the Flexible Intermediate Bulk Container (FIBC). This is very strong bags made out of woven PP straps. We modeled a multiple use and a one way FIBC with carrying capacities of 1000 kg and weights of 2500 and 2000 grams respectively [van Well, 1997].

2.7 Industrial Boxes

Industrial boxes are used for several purposes. First of all they can be used for packing loose product like fruit, vegetables and machine parts. Secondly, they can be used to pack several (cardboard) boxes or (plastic) pouches. We will define the first category as crates and the second as transport boxes.

Three types of crates can be defined that are used in Europe to ship mostly loose products like fruit, vegetables, meat and product parts. We define the plastic multiple use crate, the wooden crate and the cardboard crate. Multiple use plastic crates weigh 1.5 – 2 kg and have a volume of 40 liter according to Burggraaf (1997). A wooden crate with the same volume weighs about 2.2. kg [PFK, 1997]. Crates made from corrugated board weigh only 0.4 kg but can only be used once while the plastic and wooden crate can be used 100 and 30 times respectively [PFK, 1997, Wiemers, 1996, Pitt, 1996].

The category transport boxes differs a lot from the category ‘crates’. This is due to the fact that folding boxes made out of corrugated board are the standard. Transport boxes, as we defined them, are normally used to pack other boxes. To estimate the amount of boxes a standard box should be defined. Boxes are used in many sizes depending on the products that are packed. We will define a standard corrugated box with a volume of 40 liter and a weight of 800 gram [BV, 1996]. In 1995 the consumption of corrugated materials in Western Europe amounted 11.7 Mtonnes which leads to a total consumption of 14.6 billion boxes.

Several options are available to make a more efficient use of transport packaging. Improved gluing techniques, changes to the shape of boxes, removal of top flaps and standardization of packaging has shown that less corrugated board is needed to fulfill the same packaging service [SVM, 1992-1996]. We assume that 20% less corrugated board can be used in the future for the same service. Besides these efficiency options also substitution is possible. The most promising are the returnable transport crate and the use of industrial shrink films. Earlier in this paper we have described these options.

2.8 Pallets

The last packaging category concerns pallets. In many industrial and trade sectors pallets are used intensively for internal and external transport of products. In Europe the production of pallets amounts to 280 million pallets per year [van Belkom, 1994]. About 96% of these pallets are made out of wood. Not too long ago, almost all pallets were used for one single trip and discarded afterwards. Due to environmental legislation an obvious trend is visible towards the use of multiple-use pallets. In Germany for example, the Verpackungs-Verordnung states that the taking back of pallets by industries is compulsory. The trend towards multiple use pallets has led to a large increase of the number of pallets that are part of pallet pools. In 1994 about one third of the pallets was returnable [van Belkom, 1994].

We have modeled pallets by defining several pallets made from different materials like wood, PE, recycled PE, recycled PC, corrugated fiberboard and pressed wood fiber.

The wooden pallets can be either single or multiple trip pallets. A single trip pallets weighs about 17 kg and a multiple use pallets weighs 25 kg. The main wood type used in production is softwood. Advantages of the wooden pallet is that it is cheap (USD 5 - USD 20) and made from renewable resources. The multiple trip pallets has an estimated trip number of 40 trips.

Plastic pallets are used a lot in the food industry because they are easy to clean due to the smooth surface. Furthermore, no liquid can be absorbed by the pallets [Johnson, 1997]. The most common material for plastic pallet production in PE but in some cases also PC is used. Pallets made out of PC are stronger than PE pallets. Just like wooden pallets, plastic pallets can be used for single and multiple trips. A one-way plastic pallet weighs about 14 kg and a multiple use pallet weighs around 30 kilograms [TNO, 1994, van den Berg, 1996]. The costs of plastic pallets are higher than for wooden pallets. A PE pallet for multiple use costs around USD 75 and a pallet for single use costs about USD 12. If the pallets are made from recycled PE, they are much cheaper. The price for a multiple use recycled PE pallet starts at USD 25. Pallets that are made out of recycled PC are more expensive (USD 75) [van den Berg, 1996].For the multiple use plastic pallets we will use a trip number of 75 trips.

Pallets made from corrugated fiberboard are an option to replace single trip wooden pallets. The pallet costs about USD 6 which is cheap compared to wooden and plastic pallets [anon. 1993a]. The pallet weighs about 6 kg which makes it a very light-weight pallet. This already has been a reason for some companies to use this pallet because it reduces the weight in the trailer [Witt, 1990].

Pallets can also be made from pressed wood fibers. The advantage of these pallets is that they can save a lot of space if they are used for multiple-trip purposes because they use a fourth of the space of piled wooden pallets when stacked empty. Pressed wood fiber pallets are made out low grade fibers, mostly from bark and thinnings. The fibers are molded into a pressed wood pallet with the use of synthetic organic resins. The average costs of these pallets are about USD 5 and the average weight of the pallet amounts to 16 kg [anon., 1993a]. We will use a trip number of 5 trips per pallet.

3 Costs and energy consumption calculations

The introduction of new packaging (technology) is associated with a change in costs, both to the producer of the packaging as well as to the user (packager, transport, consumer). The viability of a material efficient packaging system will depend on the level of the costs. It is therefore, necessary to assess the costs of the various packaging systems. Furthermore changes in material use will have direct effects on energy use during production and transport of the packaging which can either strengthen or diminish the effects of different packaging system. To estimate these effects also the energy consumption of packaging making and transport should be calculated.

3.1 Cost calculations

The costs of a packaging system can be subdivided in capital costs for packaging making and filling facilities, packaging material costs, labor costs during packaging making, filling and transport, maintenance costs during production and maintenance cost of the package in case of reusable packages (collection transport etc.).

The material costs are often an important part of the total costs of packaging. These costs are calculated by the MARKAL model depending on the production technologies in different years. Investment costs for packaging making and filling facilities are based on data of several facilities built recently [Packaging Week, 1992-1997]. For returnable packaging we assume doubling of the investments and labor costs (during production) because of the extra equipment (and space) necessary for intake and cleaning. Labor costs of filling lines are estimates based on [van Vugt, 1992, 1993]. Labor costs for packaging making are estimated at 20% of total production costs. For transportation we differentiated between the costs for moving and for loading the products. For multiple use packaging we took loading costs into account for returning the package and storage costs.

3.2 Energy calculations

Energy use for packaging is generally very small, compared to the energy content of the materials and the energy use for production. We used energy consumption figures for packaging making as determined in Buwall (1991, 1996). For some types of packaging these are negligible compared to material production, e.g. corrugated box making and glass blowing [Buwall, 1996]. For returnable packaging we took the energy consumption for cleaning into account. For bottles these are estimated at 1 GJ heat and 126 MJ_{el} per 1000 bottles. Finally we took the transport energy into account for the return trip, from store to factory, of multiple trip packaging. The trip from factory to store we attributed to the packed products instead of the packaging material.

4 Results

The data collection has led to information about the characteristics of packaging used today, possible alternatives for the future, and production costs and energy consumption for all options. In order to model these aspects in MARKAL however we need to define demand categories. These demand categories are necessary in order to allows the model to substitute between different packaging categories. For example: if the demand for carbonated drinks is defined, the model may choose between metal cans, PET bottles and glass bottles to satisfy the packaging demand for carbonated drinks. In contrast: if PET bottles were defined as a demand category, substitution by metal cans or glass bottles would not be possible. In Table 4.1 the final demand categories are stated. The demand categories are chosen in such a way that they make optimal use of packaging characteristics. For example: carbonated and non carbonated drinks are two separate categories because carbonated drinks require higher CO_2 barriers from the packaging material than non carbonated drinks. To estimate the magnitude of the demand categories and the volume of all individual packaging types we made use of production statistics of consumer goods [EC, 1997] and information on packaging material consumption [e.g., PPI, 1996, APME, 1992, 1994, 1996].

For 2000 the division of packaging materials over the demand categories is predefined. For 2020 however the MARKAL model is free to use other packaging options or make shifts in the current division, taking into account maximum shares which were determined based on restriction caused by the properties of the packaging material related to the claims of the product.

Table 4.1 shows that the MARKAL model has a lot of freedom in the choices for different packaging options in 2020. The potentials have to be seen as technical potentials. We did not take any implementation barriers (next to technical ones) into account. The reason for this is that with these bounds the MARKAL model can calculate the technical potential of material efficiency and later, depending on the model results, we can give packaging options minimum bounds in order to create a more realistic scenario.

Even though the input data for the MARKAL model are stated in terms of energy consumption and costs (excluding energy consumption and costs related to materials), in Table 4.1 the CO_2 emissions and costs are stated (related to both the materials and the packaging process). These data are first order estimates because they are not a result of the MARKAL model. The process CO_2 emissions relate to the emissions during packaging making, filling and transport. The material related CO_2 emissions are calculated by using CO_2 emission factors for the different materials based on van Duin (1997). The process costs refer to the total lifecycle cost excluding material costs.

Table 4.1: The use of packaging for the demand categories as defined for the MARKAL model, including possible improvement options, possible market shares in 2020, costs and CO_2 emissions (CO_2 emissions and costs are expressed per 1000 liter packed (for pallets per 1000 trips, for carrier bags per 1000 pieces).

demand category	demand in 2000		share 2000 (%)	max. share 2020 (%)		material related CO_2 emissions (kg)	process related CO_2 emissions (kg)	material costs (ECU)	process costs (ECU)
beverages, carbonated	46	billion liter	8	100	steel bev can	128	44	45	70
			0	100	all steel can	143	47	50	70
			0	100	ultra light steel can	103	40	36	70
			8	100	aluminum bev can	250	35	64	70
			0	100	ultra light alu can	232	34	59	70
			37	50	PET one way	233	70	34	15
			6	50	PET Refill	24	43	4	26
			1	50	improved PET refill	15	43	4	26
			10	100	glass large	180	24	90	23
			27	100	glass small	300	24	150	76
			0	100	light glass	135	24	68	23
			3	100	glass refill	15	96	8	115
beverages, non carbonated	66	billion liter	20	100	glass large	180	24	90	23
			0	100	light glass	135	24	68	23
			54	80	liquid board	60	21	21	15
			26	50	PET one way	233	70	34	15
			0	30	PET Refill	24	43	4	26
			0	30	improved PET refill	15	43	4	26
			0	50	pouch	20	25	3	18
			0	50	PC bottle	20	28	2	20
dairy products, no milk	19	Mtonne	84	100	PS cup	164	62	26	44
			16	100	PP cup	168	57	17	44
			0	90	glass jar	180	24	90	45
			0	90	light glass jar	144	24	72	45
wet food	4	billion	50	100	glass jar	180	24	90	45
					light glass jar	144	24	72	45
		liter	50	100	steel food can	154	49	142	46
					honeycomb can	108	49	99	46
dry food, non susceptible	663	billion liter	8	80	cardboard box	18	13	26	19
			2	100	cardboard box + bag	20	13	30	15
			1	100	PVC box	140	13	24	39
			30	70	LDPE-film	19	8	3	18
			44	80	PP-film	19	8	2	18
			14	90	metallocene	11	8	2	18
			1	60	paper	4	7	4	18
dry food, susceptible	310	billion liter	67	100	PP-laminate	22	8	2	18
			8	100	PET-laminate	20	8	3	18
			9	100	metallocene -	14	8	2	18
			4	10	PP-metalised	11	8	1	18
			11	10	PET-metalised	11	8	2	18
			1	10	Metallocene-met.	7	7	1	18

Table 4.1 (continued): The use of packaging for the demand categories as defined for the MARKAL model, including possible improvement options, possible market shares in 2020, costs and CO_2 emissions (CO_2 emissons and costs are expressed per 1000 liter packed (for pallets per 1000 trips, for carrier bags per 1000 pieces).

demand category	demand in 2000		share 2000 (%)	max. share 2020 (%)	Packaging type	material related CO_2 emissions (kg)	process related CO_2 emissions (kg)	material costs (ECU)	process costs (ECU)
non-food liquids	10.5	billion liter	100	100	HDPE bottle	500	161	72	44
			0	100	Rec. HDPE bottle	250	161	72	44
			0	100	Pouch	50	27	7	36
			0	50	Liquid board	14	24	21	44
dry non-food	168	billion liter	14	80	Cardboard box	18	13	26	19
			10	100	PVC box	140	62	24	39
			0	20	Cardboard blister	18	13	26	39
			37	80	LDPE-film	37	8	3	18
			27	80	PP-film	27	8	2	18
			11	80	Metallocene film	22	8	2	18
			1	60	Paper	8	7	4	18
carrier bags	21.5	billion bags	85	100	PE bag	100	6	14	3
			0	100	Recycled bag	60	6	14	3
			10	100	Paper bag	28	0	26	3
			5	100	Multiple use bag	12	1	168	2
industrial bags	200	Mtonnes	82	82	PE bag	21	1	3	1
			9	9	Paper bag	3	0	2	1
			9	40	FIBC one way	10	6	1	0.3
			0	40	FIBC returnable	3	3	0.4	0
transport	1671	billion liter	16	100	Plastic crates	3	17	0.4	17
			1	20	Wooden crates	2	0	0.5	15
			1	20	Corrugated box	10	0	6	93
			32	50	Shrink foil	3	0	0.4	3
			50	100	Cardboard crate	5	0	3	93
			0	100	Improved corr. Box	8	0	5	93
pallets	5.6	billion trip units	3	100	Wood one way	17000	0	4250	2667
			60	100	Wood returnable	625	20	156	378
			37	100	PE returnable	2000	159	288	649
			0	100	PE one way	70000	4861	10080	12666
			0	100	PE recycled	1000	139	288	649
			0	100	PC recycled	1000	139	412	649
			0	100	Corrugated fiberb.	3000	0	1800	2000
			0	100	Pressed wood	3200	0	800	142
pallet wrapping	1.0	billion trip units	42	80	Shrinkcovers	5000	291	720	760
			58	100	Stretchfilm	3000	175	432	760

5 Factor 2 or factor 10?

Is it possible to reduce the CO_2 emissions related to packaging use with 50% (factor 2) or is it maybe possible to reduce the CO_2 emissions with 90% (factor 10)?

To answer these questions we need the results of the MARKAL model. However, based on the results as stated in Chapter 4 we can try to foresee what may be the result of the implementation of various options. In such an exercise we can not take into account all the effects that different options have on each other.

If we go through the packaging options as stated in table 4.1 (and background information in Chapter 2 and Hekkert et al. (1998) we can see that in general the following options are possible:

- *Lighter packaging*. This can be the result of using thinner material (foils, cans), using a different packaging shape (cans, bottles, boxes), using more efficient packaging and filling machines (boxes). To implement these options very often only small changes are necessary in the current production methods. For many packaging types that are used today, material reductions of 10 - 20% are possible.

- *Reusable packaging*. This option has a large potential in material efficiency improvement. Reusable packaging is possible for packaging of liquids (PET bottles and refillable non-food bottles) and in the field of industrial transport packaging (industrial bags, crates and pallets). Trip numbers of 20 are not uncommon which shows the large potential of this option. The savings in material consumption (and the related energy consumption) need to be compared to additional energy requirements due to washing and extra transport). Table 4.1 shows that the reduction in material requirement outweighs the increase in CO2 emission due to cleaning and extra transport. Furthermore the reduced material costs are larger than the increase in process costs.

- *Material substitution*. The effects of substitution options are very hard to describe in general because many different types of material substitution are possible and it strongly depends on other variables (e.g. energy consumption in material production, possibilities of material reuse etc.). In general two possible trends are visible. First it is possible to use much more natural organic materials that are renewable. These materials may be CO_2 neutral and therefore attractive to use from a CO_2 point of view. On the other hand these materials are often in competition with plastic packaging that can be reused which may diminish the positive effects of natural organic materials. Secondly current packaging can be substituted by light-weight alternatives (PE pouch, foils). The effects of this type of substitution depend strongly on the original material. Table 4.1 shows that both options are very useful to improve the material efficiency. Only reusable packaging seems to be a better option.

- *Use of recycled material*. In food packaging this option has limited possibilities due to regulations related to hygiene considerations. However, smart technologies make it possible to use recycled material even within this sector (e.g. multi layer PET bottles). In other sectors the use of recycled material has large potentials (pallets, crates, carrier bags). Taking into account that for plastics the feedstock may account for as much as 67% of the total energy input, energy reductions with a factor 2 are in some cases not unlikely.

When we add the possibilities of the options stated above we may conclude that a reduction in CO_2 emission with a factor 2 should definitely be possible for the product category packaging. We need to take into account that this only holds if we assume an equal consumption level because a strong growth in consumption will also lead to a strong growth in packaging consumption.

A reduction in CO_2 with a factor 10 seems not very realistic with the current identified packaging options. Even a total shift toward returnable packaging will not be enough to reach this goal. Large changes in society are necessary to reach this goal. It is beyond the scope of this paper to get into options that may result in a 90% reduction of CO_2 emissions.

6 Policy Consequences

The packaging industry is a very dynamic and innovative sector. The sector is always trying to make packaging as attractive, easy to open and strong as possible. Their first concern is that packaging needs to protect products or keep it fresh and their second concern is related to marketing considerations. Material efficiency improvement is only attractive if it saves money. Fortunately, the cost of packaging is for a substantial part related to the material input. Therefore some measures are likely to be implemented voluntarily like weight reduction of steel and aluminum cans and plastic and glass bottles.

From current European policy as stated in the Packaging Directive we may expect that the goals are reached at some point in the future. The goals as stated in the packaging directive (e.g. 25-45% recycling of packaging waste [EU, 1994]) are not very likely to reach a 50% CO_2 reduction before 2020. The second Packaging Covenant in The Netherlands goes further than the European directive. It aims for a total reduction of the amount of packaging waste to 940 ktonnes in 2000 compared to 1314 ktonnes in 1995, or a reduction of 28%. For the different packaging materials sub-covenants have been made for more detailed goals per material. Even though large waste savings may be the result of this covenant, a reduction in CO_2 emissions with a factor 2 is not likely to be the result.

In order to reach CO_2 emission reductions with a factor 2 or more in the field of packaging and to use the potential of available options a more stringent policy is needed. It is not within the scope of this paper to argue for special measures or even to indicate where to focus on. However, it seems that the effects of 'factor 2' policy on the packaging industry in The Netherlands will not be as great compared to the average European situation. This is mainly due to the fact that in The Netherlands the use of returnable packaging is much more common than in other parts of Europe. Furthermore it is very likely that 'factor 2' policy will not affect the packaging industry as much as the materials producing industries. The packaging industry will use their innovative strength to produce different packaging products (as became visible in The Netherlands during packaging covenant I) but the plastics, paper and board and the iron and steel industries will be forced to produce less than before. However, the production high value added products (e.g. ultra thin steel, high tech foils) may weaken this trend.

7 Conclusions

The packaging sector is an important sector from a material consumption point of view. The sector is responsible for about 3.3 percent of the European CO_2 emission. The most important materials used in this sector in terms of CO_2 emission are plastics, metal and paper and board.

The use of packaging materials is closely related to the use of consumer goods. The latter is likely to go through a strong growth the coming decades and therefore a growth in packaging consumption may be expected. Even though European policy by means of the Packaging

Directive is aiming at increasing the recycling targets a net increase of virgin packaging materials may be expected.

Many options are available to reduce the amount of packaging material. This paper shows that these options may lead on first sight to a reduction of CO_2 emission by the packaging sector with at least a factor 2 by the year 2020. The options will de used as input data for the Markal model in order to calculate the total CO_2 emission reduction possible.

The options dealt within this paper are specified per packaging category and by packed product category. However, in general the options can be classified by four categories: lighter (more efficient) packaging, reusable packaging, material substitution and use of recycled material.

Making more efficient use of packaging materials often leads to cost effective savings of 10 - 20% packaging material. The use of reusable packaging has great potentials. Returnable or reusable pallets, crates and PET bottles have trip numbers varying from 5 to 100 trips which has large effects on the amount of packaging material needed per packaging service. The influence of material substitution on CO_2 emissions is not clear. The MARKAL model should create more insight in this matter. The use of recycled materials is in some parts of the sector (industrial transport) very promising and in others it is more problematic (food packaging).

In terms of implementation and policy our study shows a potential of about 20% is available to reduce the amount of packaging material and related CO_2 emissions without large changes in consumer behavior or large changes in production methods. Furthermore much higher reductions can be reached with small behavioral changes. Packaging options of this type are the use of reusable and refillable packaging and the use of recycled materials.

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