GUA - Gesellschaft für umfassende Analysen
Corporation for Comprehensive Analyses

The Contribution of Plastic Products to Resource Efficiency

Estimation of the savings of energy and greenhouse gas emissions achieved by the total market of plastic products in Western Europe by means of a projection based on a sufficient number of examples

Final Report

Updated version 1.1

Vienna, January 2005

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Client:

Plastics*Europe* (formerly APME) - Association of Plastics Manufacturers(*)
www.plasticseurope.org

Contractor:

GUA Gesellschaft für umfassende Analysen GmbH
Sechshauser Straße 83, A-1150 Vienna
Tel.: +431 / 892 08 14   Fax: +431 / 892 08 82
E-Mail: office@gua-group.com   URL: www.gua-group.com

Authors:

Harald Pilz
Johann Schweighofer
Evelin Kletzer

Critical Review:

Roland Hischier, EMPA St. Gallen

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(*) **Plastics***Europe* is the newly formed plastics manufacturers association which merges APME and national plastics industry bodies into one single networked organisation. It will operate from six decentralised offices: one in Brussels and five regional centres located in France, Germany, Italy, Spain and the UK.

TABLE OF CONTENTS

FIGURES

TABLES

Abbreviations

GHG emissions	Greenhouse gas emissions

1 GOAL OF THE STUDY

Plastic products are made of energy resources. Additionally, their production needs further energy resources. Nevertheless, plastic products frequently enable energy *savings* from the perspective of the energy balance of the total life cycle compared to the energy balance of an alternative material. Examples for such energy savings by plastic products are:

- Substitution of materials which consume much more energy for production of the same functional unit (e.g. glass)
- Performance of a certain function with much less material (e.g. packaging)
- Fuel savings because of reduction in mass (transport, cars)
- Energy savings due to thermal insulation (where insulation with other materials would be less effective, technically complicated or too expensive)
- Savings of resources by avoiding losses or damage of packed products.

The purpose of this study is to estimate the savings of energy and greenhouse gas emissions achieved by the *total* market of plastic products in Western Europe by means of a projection based on a sufficient number of examples.

2 COVERAGE OF THE TOTAL MARKET OF PLASTIC PRODUCTS BY CASE STUDIES

2.1 Market data on plastic products in Western Europe

38.123.000 tonnes of plastic products have been consumed in Western Europe in the year 2002 [PlasticsEurope 2003]. To find out how well this total market of plastic products can be represented by case studies, GUA has tried to collect all detailed data available on the market shares of application sectors, of product groups within these sectors and even of the spectrum of products within a product group. A general finding was that detailed market data are very rare. Table 1 represent the most detailed split of the total market into application sectors and product groups that could be achieved for this report.

	Market data			
	1st level	2nd level	3rd level	
	share within ...			share within
	application sector	product group	product spectrum	total market
Packaging	**38,10%**			
small packaging		6,4%		2,4%
beverage bottles		12,0%		4,6%
other bottles		15,6%		6,0%
other rigid packaging		28,0%		10,7%
shrink and stretch films		9,1%		3,5%
carrier-bags		5,0%		1,9%
other flexible packaging		15,6%		5,9%
not substitutable pack.		8,3%		3,1%
Building	**17,60%**			
Pipes and ducts		39%		
drain and sewer pipes			49%	3,4%
drinking water pipes			21%	1,5%
agricultural pipes			9%	0,6%
conduit pipes			8%	0,6%
gas pipes			5%	0,3%
heating & plumbing pipes			4%	0,3%
industry pipes			4%	0,3%
Insulation		21%		3,8%
Floor & wall coverings		7%		1,2%
Windows		12%		2,2%
Profiles		6%		1,0%
Lining		5%		1,0%
Fitted furniture		9%		1,5%
Electric/electronic	**7,30%**			
cables		37%		2,7%
IT and telecommunications		22%		1,6%
large household appliances		18%		1,3%
consumer equipment		8%		0,6%
electrical equipment		7%		0,5%
small household appliances		6%		0,4%
others electric/electronic		1%		0,1%

	Market data		
	1st level	2nd level	
	share within ...		share within
	application sector	product group	total market
Automotive	**7,00%**		
interior trim		19%	1,3%
dashboard		14%	1,0%
seats		12%	0,9%
bumpers		10%	0,7%
under the bonnet components		9%	0,6%
upholstery		8%	0,5%
fuel systems		7%	0,5%
electrical components		7%	0,5%
body (including body panels)		6%	0,4%
lighting		5%	0,3%
exterior trim		4%	0,3%
others automotive		1%	0,1%
Housewares	**5,00%**		
PP housewares		33%	1,6%
HDPE housewares		12%	0,6%
PS housewares		2%	0,1%
Other housewares		54%	2,7%
Furniture	**4,00%**		
PP furniture		49%	2,0%
PS furniture		2%	0,1%
Other furniture		48%	1,9%
Agriculture	**2,50%**		
silage films		22%	0,6%
tree guards		11%	0,3%
bale twine/net wrap		10%	0,2%
vegetable film		4%	0,1%
others agriculture		52%	1,3%
Medicine	**1,70%**		
syringe		11%	0,2%
infusion container		8%	0,1%
others medicine		81%	1,4%
Others			
toys/leisure/sports	**4,00%**		4,0%
mechanical engineering	**2,13%**		2,1%
non-autom. transport	**1,67%**		1,7%
footware	**1,12%**		1,1%
ABS tools/DIY	**0,36%**		0,4%
OTHER appl. sectors	**7,52%**		7,5%
Total	**100,00%**		100,0%

Table 1: Market data on plastic products consumed in Western Europe

Sources of market data (the year to which data is referring is given in round brackets):

- Total packaging (2002): PlasticsEurope [2003].
- Beverage bottles and other bottles (2001): AJI-Europe [2003].
- Other product groups within packaging (2000): GVM [2002].
- Original data on bottles from AJI-Europe was reduced by 10 % because injection moulded products, which are no bottles, were included in the figures as well. Furthermore, the data on bottles from AJI-Europe was split into food and non-food bottles. As a case study is devoted to beverage bottles, all PET- and PVC-food bottles have been interpreted as beverage bottles. In this study there is no further differentiation between all other food bottles and non-food bottles.
- Total building (2002) and product groups within building (1995): PlasticsEurope [2003 & 1997].
- Data on pipes (2001): IAL [2002].
- Total electric/electronic sector (2002) and product groups within E&E (2000): PlasticsEurope [2003 & 2001].
- Total automotive sector (2002) and product groups within automotive sector (1998): PlasticsEurope [2003 & 1999].
- The total market share of housewares and furniture was derived from a comparison of data for the UK, France, Western Europe and the USA:
- UK-data [Waste-Watch 2003] on furniture & housewares (7,5 % of total market) for 2000 underestimate conditions in Western Europe by at least 1,1 % (result of a comparison of data for PP injected furniture for UK and Western Europe, the latter given by AJI-Europe for 2001). Therefore 9% of total plastics consumption is assumed for furniture & housewares. About 4% will be furniture (comparison of data from France and the USA; the German figure (7 %) seems to be too high). Therefore an estimate of 5% is related to housewares.
- Total plastics for agriculture (2002): PlasticsEurope [2003]. Product groups within agriculture: UK-data for 2000 [Waste-Watch 2003].
- For medical applications, the average of UK and French data was used (1,7 %). Data for syringes and infusion containers: see chapter 4.8.1.1.
- Plastics for toys/leisure/sports was derived from a comparison of data for the UK and France. Market data published by VKE (Statistik und Marktforschung: Kunststoffverbrauch Westeuropa 2000 nach Abnehmerbranchen) give for sport and leisure a share of 2 %.
- Mechanical engineering, footwear and “tools/DIY made from ABS” is data for the UK [Waste-Watch 2003].
- The ratio of automotive and non-automotive transport in the USA [Franklin 1991] was used to derive an estimate for non-automotive transport.

Despite an intense search for market data, still **15 % of the market is practically not described** (“other” in housewares, furniture, agriculture, medicine, and “Others”).

Beside this lack of data, the **biggest sectors/product groups with no more detailed information available** are:

- toys/leisure/sports (4,0 %)
- insulation (3,8 %)
- drain and sewer pipes (3,4 %)
- cables (2,7 %)
- windows (2,2 %)
- mechanical engineering (2,1 %)
- PP furniture (2,0 %).

2.2 Coverage of the total market of plastic products by case studies

2.2.1 Not realistically substitutable plastic products

This study is purely devoted to the investigation of effects on energy and GHG emissions caused by the **substitution of plastics by other materials**.

Of course, also the way *how* materials are used and *how* processes are designed in general influence the total energy demand. Cars for example became heavier to fulfil higher safety demands, resulting in higher fuel use. At the same time, more efficient engines have been developed, reducing fuel demand. Thirdly, mobility can be realised by cars as well as by other means of transport. For the general goal to use resources efficiently, all those effects have to be taken into consideration. Changes in the design of processes and services can have a bigger impact than the effect of different materials.

This study however does not question the processes used today: how goods are packed (packaging sizes, etc.), how cars are built (safety and comfort), etc. It only shows the effects, if all (substitutable) plastic products, as they are used today, would be replaced by alternative materials.

Another important prerequisite: When a plastic product is substituted by products made of a different materials, it is important for this study that both products “render the same service”, or that the difference in performance or functionality can be quantified easily. Therefore **“not substitutable” in this study generally means:**

A certain plastic product cannot be substituted by another product made of a different material without a decisive change in design or function or service rendered or in the process itself, which is delivering a certain service (see examples given below).

	Not substitutable % of sector	Not substitutable % of total market
Packaging	2,2%	0,8%
Building - Pipes	0,0%	0,0%
Building - Non Pipes	0,0%	0,0%
Electric/electronic	55,6%	4,1%
Automotive	54,5%	3,8%
Housewares	0,0%	0,0%
Furniture	0,0%	0,0%
Medicine	50,0%	0,9%
Footwear	0,0%	0,0%
Other sectors	50,0%	9,1%
Total Market		**18,6%**

Table 2: Overview of market shares, where plastic products are not realistically substitutable by other materials

In the sectors, where plastics are the only choice, they are usually not questioned as a material. Comments regarding definition and description of non substitutable plastic products in the order of relevance regarding mass:

Other sectors (50% of sector, 9,1 % of total market)

“Other sectors” are:

"Other sectors"	
toys/leisure/sports	4,0%
Agriculture	2,5%
mech. engineering	2,1%
non-autom. transport	1,7%
ABS tools / DIY	0,4%
other applications	7,5%
Total	**18,2%**

There is no data existing on the share of non substitutable plastic products in these sectors. Therefore we have **assumed** that the share is 50 %.

Examples:

Sports: Skies have been made of wood decades ago. Today no other material then the technical polymers used would guarantee the same functionality. In a comparison of plastics with other materials, other effects would be more important than different energy demands. Especially effects in the use phase would be very important (changes in performance, higher risk of injuries, etc.). Quantification of such effects would be very difficult.

Agriculture: In many cases the alternative to plastics is actually a different *process* (or a different yield), not another material: Silage films have partly substituted the process of producing hay. Vegetable films enable higher yields on rather infertile land (reduction of humidity losses). Geo-membranes prevent water losses in canals for irrigation. None of these products has substituted or could be substituted by other *materials*.

Electric & electronic sector (56% of sector, 4,1 % of total market)

We have assumed that plastics used for insulation of cables, for “electrical equipment”, for electronics and for “small components” are not substitutable by other materials. Market shares of the first two categories are given by PlasticsEurope [2001]. Electronic parts come to 13 % of the total plastics used in E&E equipment [ZVEI 1992]. The total amount of electronic parts and not substitutable small parts is estimated at 20 %.

Automotive sector (55% of sector, 3,8 % of total market)

A study of Heyde & Nürrenbach [1999] investigated the possibilities to substitute plastic parts in cars. The results show that only 45 % of plastics used in cars can be substituted by other materials without changing the function of the components decisively. All other plastic parts render services, which could not be provided by other materials or could only be provided by using a completely changed principle of function/operation/design. Examples: Airbag, seat construction.

Packaging sector (2,2 % of sector, 0,8 % of total market)

A very detailed study of GVM [2004] investigated the possibilities to substitute plastic packaging in Germany by other materials. One of the results was the identification of 2,2 % of not substitutable plastic packaging in Germany, which is used as an estimate for Western Europe in this study. Most important parts of non substitutable plastic packaging are small boxes/containers, wrapping films and pouches (e. g. packaging for fresh meat), dispenser tops/caps, medical blister packaging, etc.

Medical sector (50 % of sector, 0,9 % of total market)

No data is available regarding the share of non substitutable plastic products; 50 % are assumed.

2.2.2 Coverage of total market by case studies

The following table gives an overview of the case studies identified and analysed in this report. In the light of available data it was not possible to define and calculate further case studies.

	Number of case studies	Number of analysed products	Case study titles (analysed product groups)
Packaging	7	60	small packaging; beverage bottles; other bottles; other rigid packaging; shrink and stretch films; carrier-bags; other flexible packaging
Building except pipes	3	10	insulation; flooring; windows
Pipes	9	54	big drain & sewer pipes; small drain & sewer p.; big drinking water p.; small drinking water p.; agricultural p.; conduit p.; gas p.; heating & plumbing p.; industry p.
Electric/ electronic	2	9	housing; insulation in refrigerators
Automotive	3	18	under the hood; exterior & cockpit; other automotive parts
Housewares	3	8	keep fresh boxes; buckets; waste bins
Furniture	2	7	garden furniture; matresses
Medicine	2	4	syringe; infusion container
Footware	1	4	soles
Total	**32**	**174**	

Table 3: Case studies analysed in this report.

	Polymers covered by case studies	Alternative materials covered by case studies
Packaging	LDPE; HDPE; PP; PVC; PS; EPS; PET	Tin plate; Aluminium; Glass; Corrug. Board & Cardboard; Paper & fibre cast; Paperbased composites; Wood
Building except pipes	PVC; XPS; EPS; PUR	Aluminium; Foamglass; Wood; Linoleum, Mineral wool
Pipes	HDPE; PP; PVC; PE-X; ABS/SAN	Steel; Zinc coated iron; Cast iron; Aluminium; Copper; Fibrecement; Stoneware; Concrete
Electric/ electronic	PP; HIPS; ABS/SAN; PUR	Steel; Aluminium; Mineral wool; Wood; Rubber
Automotive	HDPE; PP; PMMA; PA; ABS/SAN; PUR	Steel; Aluminium; Glass; Rubber
Housewares	HDPE; PP	Steel; Zinc coated iron; Aluminium; Glass
Furniture	PP; PUR	Steel; Aluminium; Wood; Latex
Medicine	PP; PVC	Glass
Footware	PVC; PUR	Leather; Rubber

Table 4: Polymers and alternative materials considered in each case study

The decision to put a special focus on pipes has several reasons: Pipes are the most important product group on the plastics market (6,9 %; see Table 5). If we additionally take into account that all packaging applications are well covered for the purpose of this study by a very detailed substitution model of GVM and that cables are excluded from the scope of this study (see above), the second biggest (non-packaging) product group is insulation with 3,8 % followed by windows with 2,2 %. The various application sectors of pipes, the variety of diameters and alternative materials and the wide range of possible mass ratios (mass of alternative product divided by mass of plastic product) made it necessary to choose at least 9 case studies for pipes. Finally, in the study by Franklin on the resource efficiency of plastic products in the sectors of building and transport, 71 % of the total result in the building sector was associated with pipes.

All major polymers are well represented by the case studies listed above. For the definition of every case study the actual market share of polymers used today was considered.

Chapter 4 describes the market shares that are represented by the case studies. Based on this data, the following table gives an overview of non substitutable plastic products, substitutable plastic products that are not covered by the case studies analysed and the market share of plastic products that are covered by the case studies analysed.

75 % of substitutable plastic products are covered by the case studies of this report.

	Market volume	Market share	Not substitutable	Substitutable but not covered by case studies	Substitutable and covered by case studies	Not substitutable	Substitutable but not covered by case studies	Substitutable and covered by case studies
	1.000 Tonnes	% of total market	% of sector	% of sector	% of sector	% of total market	% of total market	% of total market
Packaging	14.520	38,1%	2,2%	0%	98%	0,8%	0,0%	37,3%
Building - Pipes	2.640	6,9%	0,0%	0%	100%	0,0%	0,0%	6,9%
Building - Non Pipes	4.070	10,7%	0,0%	33%	67%	0,0%	3,5%	7,2%
Electric/electronic	2.780	7,3%	55,6%	28%	16%	4,1%	2,0%	1,2%
Automotive	2.670	7,0%	54,5%	0%	45%	3,8%	0,0%	3,2%
Housewares	1.910	5,0%	0,0%	50%	50%	0,0%	2,5%	2,5%
Furniture	1.520	4,0%	0,0%	50%	50%	0,0%	2,0%	2,0%
Medicine	650	1,7%	50,0%	31%	19%	0,9%	0,5%	0,3%
Footwear	430	1,1%	0,0%	56%	44%	0,0%	0,6%	0,5%
Other sectors	6.930	18,2%	50,0%	50%	0%	9,1%	9,1%	0,0%
Total Market	**38.120**	**100,0%**				**18,6%**	**20,3%**	**61,0%**

Table 5: Non substitutable segments of the market of plastic products; coverage of substitutable plastics by case studies

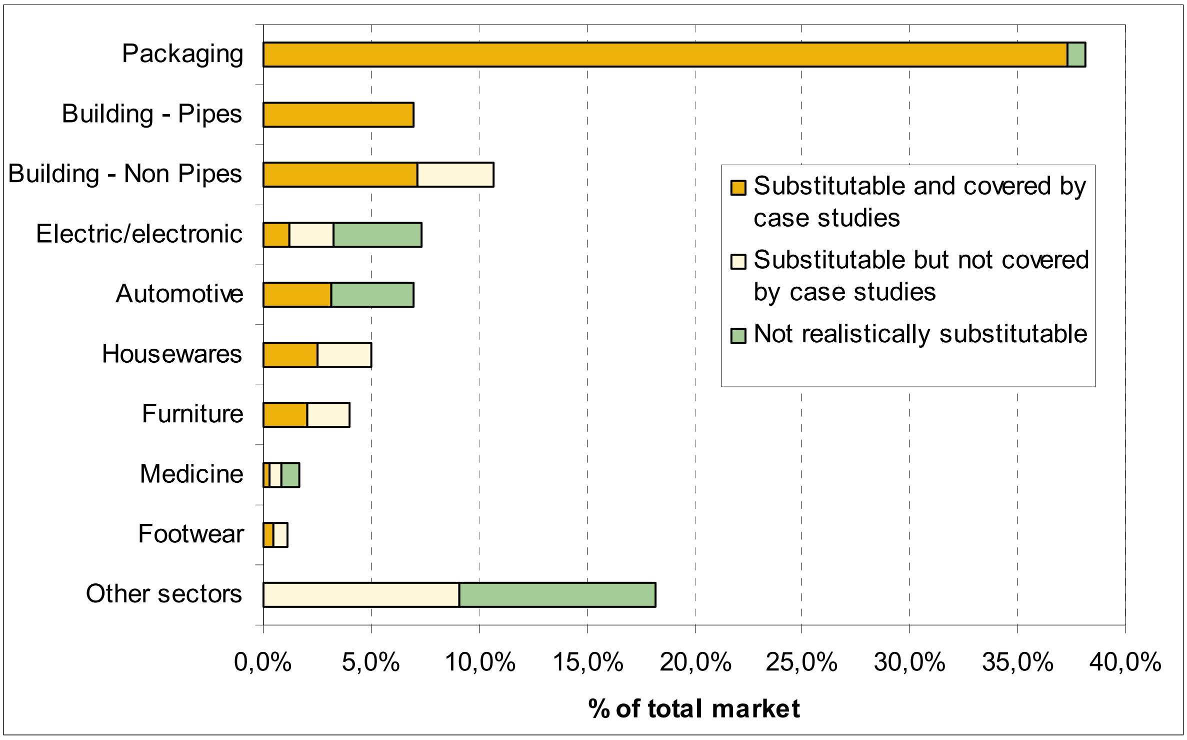

Figure 1: Non substitutable segments of the market of plastic products; coverage of substitutable plastics by case studies

Sectors where identification and definition of case studies is very difficult at present:

- Toys/leisure/sports (4 % of the total market)
- Fitted furniture, lining (2,5 %)
- Mechanical engineering (2,1 %)
- Substitutable plastics in the E&E sector beside housings (2 %)
- Non automotive transport (1,7 %)
- Substitutable plastics in the agricultural sector (1,3 %)
- Profiles - building (1 %)
- Other applications in medicine (0,7%).

3 CALCULATION MODEL

Data on energy demand and greenhouse gas emissions in the total life cycle of the products investigated in this study were generated in a calculation model built in "Excel". Figure 2 gives an overview of the structure and the elements of the calculation model.

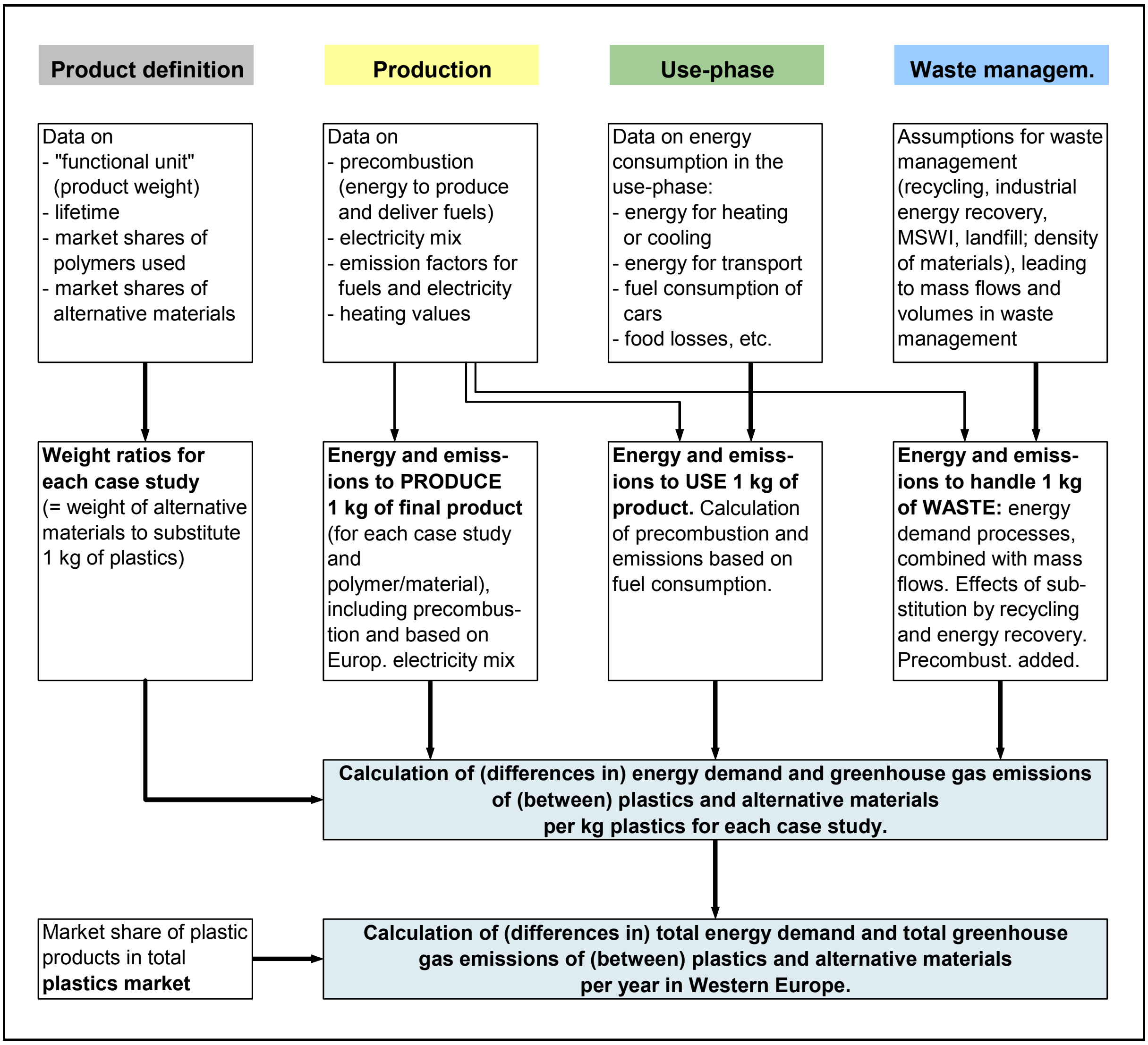

Figure 2: Schematic structure of the calculation model to generate data regarding energy demand and greenhouse gas emissions in the total life cycle of the products investigated.

3.1 General comments regarding the calculation model and the data used

Calculations for the analysed case studies cover the total life-cycle: production, effects in use and waste management. Energy and emission data include the effects of the “precombustion” phase, i.e. production and delivery of fuels. Energy demand given in Joule is always based on the gross heating values of fuels.

For production of electricity, the European electricity mix (UCPTE) is used. Data from existing studies for the production phase is in most cases already based on the UCPTE electricity mix or is transformed to this electricity mix, if possible.

Calculations within a case study are always based on the same functional unit, i.e. mass of a certain material needed to render the same service (packaging material to pack a certain amount of goods; window frames for the same window size; 1 m^2 of floor covering; etc.). In some case studies, different lifetimes of plastic products and alternative materials are assumed additionally.

If the plastic product is made of different polymers, then the market shares of the relevant polymers is considered. If more than one alternative material could possibly substitute the plastic product analysed, then also the market shares of the relevant alternative materials are included in the calculations (see Figure 2, section “product definition”).

Data for the production of the products investigated are generally taken from existing ecobalance studies. Calculations of effects of the use phase and within waste management were based on the fuel demand of the relevant processes. Precombustion energy is added to the fuels needed to get the total energy demand. GHG emissions are calculated by multiplying fuel demand with emission factors (the emission factors include emissions from the precombustion phase). See Figure 2, sections “production, use-phase, waste management”.

Two different scenarios were used to characterize the waste management phase (assumptions for recycling rates, energy recovery and landfill shares): The “base case”, representing the status quo, and the “future case” with slightly increased recycling rates, more energy recovery and less landfill.

Waste management calculations also include the credits of recycling and energy recovery in form of the substituted primary production and the substituted fossil fuels or substituted energy conversion.

Based on the steps described above, energy and emission data are calculated for production, use and waste management **per kg product** made of a certain material (see Figure 2, middle section).

To compare the energy and emission data of a certain plastic product and its possible alternatives made of different materials, the data for alternative materials are combined with the respective mass ratios (definition of mass ratios: see below).

Data needed to calculate the mass ratios needed are taken form existing ecobalance studies comparing different materials (derived from mass data for functional units) of from own investigations (see description of case study specific data in next chapter).

Finally the results of the case studies analysed are aggregated with regard to the market shares of plastic products on the total plastics market in Western Europe. The final results are (differences in) energy demands and GHG emissions caused by the investigated products in Western Europe (see Figure 2, bottom section).

The final results for the case studies and the total market are subdivided into figures for the main fuels (coal, oil, gas, hydro, nuclear, lignite, wood/biomass, petrol/diesel, fuel oil extra light, other) and the emissions considered (CO_2, CH_4 and N_2O). Furthermore, energy demand and emissions are shown separately for the life cycle stages production, use, and waste management.

3.2 Definition of mass ratios

The mass ratios give the mass of alternative materials which are needed to substitute 1 kg of plastics for a certain product.

Case 1: Plastic product is made of only 1 polymer (mass P), possible alternative is only one material (mass A).

Mass ratio = mass of alternative product divided by mass of plastic product =
= mass A / mass P.

(Masses have to be based on functional units.)

Saved energy per kg plastic product =
= energy per kg alternative product x mass ratio – energy per kg plastic product

Case 2: Plastic product can be produced from 2 (or more) polymers; possible alternative can be produced from 2 (or more) materials

Mass P = mass P1 x market share P1 + mass P2 x market share P2

Mass ratio 1 = mass A1 x market share A1 / mass P

Mass ratio 2 = mass A2 x market share A2 / mass P

(Masses and market shares have to be based on functional units.)

(Market share P1 + market share P2 = 100%;
market share A1 + market share A2 = 100%)

Saved energy per kg plastic product =
+ energy per kg A1 x mass ratio 1 + energy per kg A2 x mass ratio 2
– energy per kg P1 x market share P1 – energy per kg P2 x market share P2

Case 3: Plastic product contains also other materials:

In the case studies window frame and flooring the "plastic product" also contains other materials: In this study, PVC flooring consists of 33 % PVC, 17 % additives and 50 % fillers; the PVC window profile contains 61 % PVC, 15 % additives and 24 % steel.

Data in the production database is given per kg product. To get results per kg pure plastics (later these results are multiplied with pure plastic masses, not with product masses in Western Europe), the energy per kg (plastic) product has to be divided by the plastics share in the product:

(Energy / kg product) / (kg plastics / kg product) = energy / kg plastics

Example:

PVC flooring: 3,8 kg/m2. Linoleum flooring: 3,45 kg/m2. PVC-content in PVC flooring: 33,3 %.

On the level of products, the mass ratio table (see table Table 6) would show “1” for the plastic product and 3,45 / 3,8 = 0,908 for the alternative product.

To get energy results per kg plastics (from energy per kg product in the database), both values are multiplied with 1/0,333 leading to a factor of 3,00 for PVC flooring and 2,73 for Linoleum flooring.

Case 4: Plastic mass in case study is lower than equivalent plastic mass on the real market:

In the case study beverage packaging, a higher share of PET refillable bottles is assumed (30 % of total filling volume, varied between 10 % and 50 %) than on the real market today, where about 9 % of the total filling volume is filled in PET refillable bottles (see chapter 4.1.2). The higher proportion of PET refillable bottles leads to a lower PET mass for beverage packaging than on the current market. The respective PET mass in the theoretical scenario is only 83 % of the PET on the current beverage packaging market.

Therefore, the results per kg PET have to be multiplied with 0,83 before they can be multiplied with the total mass of PET in Western Europe to give the total result for Western Europe.

As a consequence, the table of mass ratios contains 0,83 as a multiplying factor for the energy data per kg PET instead of the factor “1” in the other case studies. In the same way the mass ratios for the alternative materials are multiplied with 0,83.

Table Table 6 and Table 7 show an overview on the case studies analysed, on the market shares of plastic products within a case study made of different polymers and on mass ratios (mass of alternative material to substitute 1 kg of plastics) in the calculation model.

Table of mass ratios	**Market share plastics**	**Plastics total**	LDPE	HDPE	PP	PVC	PS	EPS	PET	**PE-X**, PMMA	**ABS**/SAN & oth. thermopl.	PUR	Other thermosets
small packaging	2,45%	**1,00**	0,18	0,04	0,31	0,10	0,28		0,08				
beverage bottles	4,57%	**0,83**							0,83				
other bottles	5,95%	**1,00**	0,01	0,60	0,16	0,01			0,23				
other rigid packaging	11,18%	**1,00**		0,32	0,35	0,01	0,25	0,08					
shrink and stretch films	5,85%	**1,00**	1,00										
carrier-bags	1,13%	**1,00**	1,00										
other flexible packaging	6,13%	**1,00**	0,51		0,41	0,06	0,02						
big drain & sewer pipes	1,69%	**1,00**		0,15	0,10	0,75							
small drain & sewer pipes	1,69%	**1,00**		0,15	0,10	0,75							
big drinking water pipes	0,73%	**1,00**		0,40		0,56				0,04			
small drinking water pipes	0,73%	**1,00**		0,40		0,56				0,04			
agricultural pipes	0,62%	**1,00**		0,15	0,10	0,75							
conduit pipes	0,55%	**1,00**		0,05		0,95							
gas pipes	0,35%	**1,00**		1,00									
heating & plumbing pipes	0,28%	**1,00**			0,45					0,55			
industry pipes	0,28%	**1,00**		0,50	0,06	0,29				0,03	0,12		
Insulation	3,76%	**1,00**					0,13	0,42				0,44	
Floor (& wall) coverings	1,23%	**3,00**				3,00	(XPS)						
Windows	2,16%	**1,63**				1,63							
housing	1,05%	**1,00**			0,25		0,27				0,47		
insulation in refrigerators	0,14%	**1,00**					(HIPS)					1,00	
Under the hood	1,45%	**1,00**		0,38	0,37					(PMMA)	0,25	(PA-GF)	
Exterior & cockpit	0,96%	**1,00**			0,75					0,10	0,15		
Other automotive parts	0,77%	**1,00**			0,12						0,13	0,74	
Keep fresh boxes	1,50%	**1,00**			1,00								
Buckets	0,50%	**1,00**			1,00								
Waste bins	0,50%	**1,00**		1,00									
Garden furniture	1,40%	**1,00**			1,00								
Matresses	0,60%	**1,00**										1,00	
syringe	0,19%	**1,00**			1,00								
infusion container	0,14%	**1,00**				1,00							
soles	0,50%	**1,00**				0,77						0,23	

Table 6: Mass ratio model – plastic products

Table of mass ratios	**Altern. mat. - Total**	Steel	Zinc coated iron	Cast iron	Steel / tin plate	Aluminium	Copper	Glass	Fibrecement	Stoneware	Concrete	Corrug. Board / Cardboard	Paper / fibre cast	Paperbased composites	**Wood**, textile, etc.	Other
small packaging	3,35				0,33	0,15		1,45				0,24	0,72	0,24	0,21	
beverage bottles	8,70				0,08	0,03		8,52						0,06		
other bottles	5,24				0,92	0,02		4,25						0,06		
other rigid packaging	1,73				0,37	0,09		0,14				0,22	0,26	0,29	0,35	
shrink and stretch films	5,98				0,77							3,81	1,03	0,04	0,34	
carrier-bags	2,64												2,64			
other flexible packaging	2,23				0,33	0,00		0,05				0,05	0,74	0,64	0,42	
big drain & sewer pipes	11,75			0,32					0,19	2,22	9,02					
small drain & sewer pipes	4,58	0,18		1,59		0,07			1,52	1,22						
big drinking water pipes	3,70			2,10			0,78		0,83							
small drinking water pipes	4,54	0,45	2,67				1,42									
agricultural pipes	4,58	0,18		1,59		0,07			1,52	1,22						
conduit pipes	4,34	4,34														
gas pipes	6,63	1,34	5,29													
heating & plumbing pipes	2,77	0,81		0,93			1,03									
industry pipes	3,71	0,96		1,76		0,29	0,70									(Mineral wool)
Insulation	3,47							2,31							(Linoleum)	1,16
Floor (& wall) coverings	2,73							(Foamglass)							2,73	
Windows	0,92					0,33									0,59	
housing	2,07	0,65				0,55		(Mineral wool)							0,38	0,50
insulation in refrigerators	1,11							1,11								(rubber)
Under the hood	1,48	1,14				0,34										
Exterior & cockpit	1,57	1,07				0,28		0,23								(rubber)
Other automotive parts	1,36	0,31				0,10		0,15								0,80
Keep fresh boxes	3,93	0,41				0,32		3,19								
Buckets	3,56		3,56													
Waste bins	2,25		2,25													
Garden furniture	3,66	1,62				0,81									1,23	(latex)
Matresses	1,43	0,16														1,27
syringe	0,12							0,12								
infusion container	9,83							9,83							(leather)	(rubber)
soles	1,16														0,20	0,96

Table 7: Mass ratio model – alternative materials

3.3 General data on energy and GHG emissions

The following tables show general data used to generate, transform and complete energy and emission data in the calculation model.

	Unit	MJ/Unit
Natural (crude) fuels		
crude oil	kg	45,6
natural gas	m3	39,0
natural coal	kg	19,0
natural lignite	kg	9,5
wood (dry)	kg	16,9
uranium	g	451,0
End use fuels		
heavy fuel oil	kg	42,3
fuel oil extra light	kg	45,4
petrol	kg	45,8
diesel	kg	45,4
gas	m3	40,2
coal	kg	30,3
lignite	kg	9,9
wood (dry)	kg	16,9

Table 8: Gross heating values of natural and end-use fuels. Source: ETH & EMPA [1996]

		electricity	**natural coal**	**crude oil**	**natural gas**	**hydro-power**	**nuklear (uranium)**	**natural lignite**	**wood (dry)**
	Unit	MJ	kg	kg	Nm3	MJ	g	kg	kg
Electricity									
Primary resources incl. precombustion	Unit		0,0354	0,0081	0,0061	0,1980	0,0031	0,0449	0,0004
per MJ electric power	**MJ**		0,6726	0,3707	0,2367	0,1980	1,3756	0,4266	0,0074
Coal									
Primary resources incl. precombustion	Unit		**1,5700**	0,0435	0,0035	0,0000	0,0012	0,0180	
per 1 kg coal	**MJ**		29,8300	1,9836	0,1353	0,0000	0,5547	0,1710	0,0000
per 1 MJ coal	**MJ**		0,9845	0,0655	0,0045	0,0000	0,0183	0,0056	0,0000
Heavy fuel oil									
Primary resources incl. precombustion	Unit	0,6410	0,0227	**1,1352**	0,0039	0,1269	0,0020	0,0288	
per 1 kg heavy fuel oil	**MJ**		0,4311	51,7656	0,1517	0,1269	0,8817	0,2734	0,0000
per 1 MJ heavy fuel oil	**MJ**		0,0102	1,2238	0,0036	0,0030	0,0208	0,0065	0,0000
Natural Gas									
Primary resources incl. precombustion	Unit	0,0015	0,0001	0,0000	**0,0300**	0,0003	0,0000	0,0001	
per 1 MJ natural gas	**MJ**		0,0010	0,0005	1,1684	0,0003	0,0020	0,0006	0,0000
per 1 MJ natural gas	**MJ**		0,0010	0,0005	1,1684	0,0003	0,0020	0,0006	0,0000
Fuel oil extra light									
Primary resources incl. precombustion	Unit	0,4410	0,0156	**1,1036**	0,0027	0,0873	0,0013	0,0198	
per 1 kg fuel oil extra light	**MJ**		0,2966	50,3235	0,1044	0,0873	0,6066	0,1881	0,0000
per 1 MJ fuel oil extra light	**MJ**		0,0065	1,1084	0,0023	0,0019	0,0134	0,0041	0,0000
Diesel									
Primary resources incl. precombustion	Unit	0,4420	0,0156	**1,1036**	0,0027	0,0875	0,0013	0,0198	
per 1 kg diesel	**MJ**		0,2973	50,3239	0,1046	0,0875	0,6080	0,1885	0,0000
per 1 MJ diesel	**MJ**		0,0065	1,1085	0,0023	0,0019	0,0134	0,0042	0,0000
Industrial steam									
Primary resources incl. precombustion	Unit		0,1612	0,2501	0,5453	0,0153	0,0421	0,0023	0,0005
per 1 MJ steam	**MJ**		0,1612	0,2501	0,5453	0,0153	0,0421	0,0023	0,0005
per 1 MJ steam	**MJ**		0,1612	0,2501	0,5453	0,0153	0,0421	0,0023	0,0005

Table 9: Energy demand to produce and deliver 1 MJ of certain end-use fuels. These values are used to add precombution energy to end use fuels. Source: ETH [1996]; inventories of PlasticsEurope for industrial steam.

	CO2	CH4	N2O
	g	g	g
Electricity			
Emissions from precombustion per MJ el.	**139,836**	**0,259**	**0,000**
Coal			
Emissions from precombustion per kg coal	186,430	4,390	0,000
Emissions from precombustion per MJ coal	6,153	0,145	0,000
Emissions from combustion per MJ coal	88,480	0,010	0,001
Total emissions per MJ coal	**94,633**	**0,155**	**0,001**
Heavy fuel oil			
Emissions from precombustion per kg heavy fuel oil	634,000	4,620	0,000
Emissions from precombustion per MJ heavy fuel oil	14,988	0,109	0,000
Emissions from combustion per MJ heavy fuel oil	73,664	0,002	0,001
Total emissions per MJ heavy fuel oil	**88,652**	**0,111**	**0,001**
Natural Gas			
Emissions from precombustion per MJ natural gas	6,033	0,150	0,000
Emissions from precombustion per MJ natural gas	6,033	0,150	0,000
Emissions from combustion per MJ natural gas	53,807	0,002	0,000
Total emissions per MJ natural gas	**59,840**	**0,152**	**0,000**
Fuel oil extra light			
Emissions from precomb. per kg fuel oil extra light	502,900	4,430	0,000
Emissions from precombustion per MJ fuel oil extra light	11,077	0,098	0,000
Emissions from combustion per MJ fuel oil extra light	69,599	0,001	0,001
Total emissions per MJ fuel oil extra light	**80,676**	**0,099**	**0,001**
Diesel			
Emissions from precombustion per kg diesel	505,000	4,430	0,000
Emissions from precombustion per MJ diesel	11,123	0,098	0,000
Emissions from combustion per MJ diesel	69,824	0,003	0,010
Total emissions per MJ diesel	**80,947**	**0,101**	**0,010**
APME-steam			
Emissions from precombustion per MJ steam	8,030	0,132	0,000
Emissions from combustion per MJ steam	62,028	0,003	0,000
Total emissions per MJ steam	**70,058**	**0,135**	**0,000**

Table 10: GHG emissions caused by the consumption of 1 MJ of certain end-use fuels, including effects of precombustion. Source: Source: ETH [1996]; inventories of PlasticsEurope for industrial steam.

(Comment: After completion of this report, a more recent version of data to produce and deliver 1 MJ of certain fuels (Ecoinvent 2004) was tested in the calculation model. The resulting changes were an increase of the total energy saving of plastic products by 0,14 % and a decrease in the saved CO_2 emissions by 0,06 %. These changes are very small compared to the overall uncertainty range of the result; therefore this possible update of data to produce and deliver 1 MJ of fuels was not implemented in the updated version of this report.)

X% of electricity is produced in plants using:	
coal	17,5%
oil	9,7%
gas	9,8%
hydropower	15,2%
nuclear power	36,9%
lignite	10,5%
other	0,4%

Table 11: "Electricity mix" used in the calculation model of this study. Source: Ökoinventare Energiesysteme, Strommix, S12, Tab. XVI.3.1

Industrial steam is produced by:	
coal	16,1%
oil	25,0%
gas	54,5%
hydro	1,5%
nuclear	4,2%
lignite	0,2%
wood / biomass	0,1%
other	9,4%

Table 12: Fuels to produce industrial steam in the calculation model of this study. Source: Inventories published by PlasticsEurope.

Greenhouse gases considered:

- CO_2
- CH_4
- N_2O

CO_2-equivalents (for 100 years) for CH_4 and N_2O are 23 and 296 respectively [Ecoinvent 2003].

CO and Hydrocarbons beside methane are not considered because of their low CO_2-equivalent values (2 and 3 respectively), and because at the same time they are trace emissions with no relevant quantities beside CO_2.

3.4 Data used for waste management calculations

For all case studies, waste management calculations are carried out by GUA. The calculations within the waste management phase include:

- Definition of available amount of waste: For most case studies, the available waste is equal to the amount put on the market.[1] Only for some pipe applications and for insulation used underground it is assumed, that the product is (partly) left in the ground.
- For the waste available the proportions for recycling, energy recovery, MSWI and landfill are defined.
- The following calculations include processes of collection, sorting, recycling, energy recovery and disposal. Losses during sorting and recycling processes are taken into account.
- Recycling and energy recovery processes lead to substitution effects: By using the products of recycling processes, some part of the respective primary production process can be substituted. The "substitution factors" used describe the ratio "amount of substituted primary product" divided by "amount of recycling product". By energy recovery from combustible waste, the use of coal, oil or gas can be reduced or some conventional electricity generation can be substituted.

The energy demand and emissions of the waste processes for collection, sorting, recycling, recovery and disposal, given per tonne input material, are combined with a simple mass balance to calculate the total effects for 1 kg of available waste for a certain product ("direct fuels"). In a second step, the fuels substituted and the electricity generated due to energy recovery and MSWI are subtracted.

The third step converts electricity and steam into the respective primary fuels, and adds the energy of the precombustion phase to the other fuels. This is done by using the values given in Table 9. As a result of this procedure, the first two lines of the table given below are transformed to the third line.

Finally, the credits of fuels related to the substituted primary production are taken into account (fourth line). For the total result, the values of the third and forth line are summed up. Table 13 shows an example of the final aggregation of the energy effects within waste management (PET bottles).

	electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
	MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
direct fuels	*0,36*				*0,32*					*1,51*		
substituted fuels	*-1,15*		*-3,84*	*-1,92*	*-0,64*							
direct & subst. fuels incl. precomb.			-4,32	-1,22	-0,59	-0,16	-1,18	-0,36				
substituted material production			-2,69	-14,07	-7,05	-0,10	-1,30	-0,08	-0,01			-0,22
Total			**-7,02**	**-15,30**	**-7,64**	**-0,26**	**-2,48**	**-0,45**	**-0,01**			**-0,22**

Table 13: Final aggregation of energy effects within waste management for PET bottles.

GHG emissions of the waste management phase are calculated following similar steps: First, the GHG emissions caused by the "direct" and substituted fuels are calculated using the emission factors described in the previous chapter. Then the CO_2 emissions coming

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[1] As this study covers the total life cycle of products, it is not relevant, *when* the product becomes waste. Today, waste amounts are often smaller then the amounts consumed in the same year, if the product has a long lifetime. In this study, this difference is not relevant.

from fossil carbon in incinerated waste materials are added. In a third step, CH4 emissions from landfills are calculated (only for paper, wood and linoleum). Finally the credits of emissions from the substituted primary production are taken into account. Table 14 shows an example of the final aggregation of the energy effects within waste management (cardboard packaging).

	CO2	CH4	N2O
	mg	mg	mg
emissions from electr./steam/fuels	-541.705	-908	10
CO2 from incinerated waste	702.778		
CH4 from landfill (wood, paper)			
subst. production emissions	-1.014.394	-3.322	0
Total	**-853.321**	**-4.231**	**10**

Table 14: Calculation of GHG emissions within waste management for cardboard packaging.

Waste management processes considered in the calculation model:

- Residual waste collection
- Bulky refuse collection
- Domestic/commercial separate collection (1,1 m3 container)
- Commercial waste collection (8 m3 container)
- Sorting plastics
- Sorting paper
- Shredder plastics
- Shredder metals
- Aluminium recycling
- Tin plate recycling
- Steel / cast iron recycling
- Copper recycling
- Paper packaging recycling (product: middle layer of corrugated cardboard)
- Paper packaging recycling (product: cardboard)
- Mechanical recycling plastics 1 (including washing, producing granulate)
- Mechanical recycling plastics 2 (PET recycling)
- Mechanical recycling plastics 3 (no washing, fine grinding)
- Industrial energy recovery (including fuel preparation)
- Municipal solid waste incineration
- Landfill

3.4.1 Overview on waste management assumptions

Two different scenarios were used to characterize the waste management phase regarding assumptions for recycling rates, energy recovery and landfill shares: The “base case”, representing the status quo, and the “future case” with slightly increased recycling rates, more energy recovery and less landfill.

The status quo recycling rates for the main *application sectors* of plastics were given by PlasticsEurope: 23 % for packaging, approx. 9 % in the building sector, 6 – 7 % in the automotive sector, about 5 % in the E&E sector and 2 % for other application sectors. Slightly higher recycling rates, used for the “future case”, were also proposed by PlasticsEurope.

The plastics recycling rates for all *case studies* investigated were estimated in such a way that the weighted sum match the recycling rates given for the total sectors and that the relations between the case studies are reasonable.

Recycling rates of other materials for a theoretical substitution were estimated based on ranges of recycling rates currently reached by those materials in the EU. Especially in the packaging sector it should be noted that the recycling rates used relate to packaging which would substitute plastic packaging. Therefore they can differ from the average recycling quotas currently reached in the EU.

The assumed recycling rates for the case studies analysed are shown in Table 22 and in Table 24. The following tables show the aggregated recycling rates for the main application sectors of plastics resulting from the recycling rates assumed for the case studies analysed.

To calculate the recycling rates of total market sectors, assumptions for waste from substitutable plastic products not covered by case studies and for not substitutable products had to be made:

- Packaging: same recycling rates than for substitutable packaging
- Cables in E&E: 10 % recycling in base case, 15 % recycling in future case.
- 0 % recycling for all other waste from substitutable plastic products not covered by case studies and from not substitutable products.

The table below shows 24 % recycling rate for plastic packaging. 1 % of this figure is caused by the higher share of refillable beverage packaging in the theoretical substitution model used in this study (see chapters 3.2 and 4.1.2.1). The remaining recycling rate of 23 % matches with the recycling quota realised for plastic packaging in the EU in 2002, which was 23 % (Source: European Commission, DG ENV).

Further on, the table below shows 11,8 % recycling rate for the building sector. 2,7 % of this figure is caused by the recycling of the steel content of PVC frames. The remaining recycling quota for available plastics waste in the building sector is 9 %.

	Market share	Available waste	**Share within total waste**	Recycling rate of available waste of case studies	Recycling rate of available waste of applic. sector
Packaging	38%	100%	**42%**	24,0%	**24,0%**
Building - Pipes	7%	**37%**	**3%**	12,3%	12,3%
Building - Non Pipes	11%	**53%**	**6%**	17,3%	11,6%
Electric/electronic	7%	100%	**8%**	6,2%	**4,8%**
Automotive	7%	100%	**8%**	14,3%	**6,5%**
Housewares	5%	100%	**6%**	16,0%	8,0%
Furniture	4%	100%	**4%**	5,0%	2,5%
Medicine	2%	100%	**2%**	0,0%	0,0%
Footwear	1%	100%	**1%**	0,0%	0,0%
Other sectors	18%	100%	**20%**	0,0%	0,0%
Total Market	**100%**	**91%**	**100%**	**14,2%**	**12,6%**
Total building					**11,8%**
Total Other (Housewares ... Other)					**1,7%**

Table 15: Aggregated recycling rates for the main application sectors of plastics resulting from the recycling rates assumed for the case studies analysed – base case. Recycling rates assumed for the case studies analysed are shown in Table 22.

	Market share	Available waste	**Share within total waste**	Recycling rate of available waste of case studies	Recycling rate of available waste of application sector
Packaging	38%	100%	**42%**	26,5%	**26,5%**
Building - Pipes	7%	**37%**	**3%**	16,1%	16,1%
Building - Non Pipes	11%	**53%**	**6%**	27,8%	18,6%
Electric/electronic	7%	100%	**8%**	10,6%	**7,3%**
Automotive	7%	100%	**8%**	21,4%	**9,7%**
Housewares	5%	100%	**6%**	20,0%	10,0%
Furniture	4%	100%	**4%**	20,0%	10,0%
Medicine	2%	100%	**2%**	0,0%	0,0%
Footwear	1%	100%	**1%**	0,0%	0,0%
Other sectors	18%	100%	**20%**	0,0%	0,0%
Total Market	**100%**	**91%**	**100%**	**17,8%**	**15,1%**
Total building					**17,8%**
Total Other (Housewares ... Other)					**3,0%**

Table 16: Aggregated recycling rates for the main application sectors of plastics resulting from the recycling rates assumed for the case studies analysed – future case. Recycling rates for the case studies analysed are shown in Table 24.

For the waste amounts not going to recycling, the following distribution to industrial energy recovery, MSWI and landfill has been assumed. In the following table, industrial energy recovery and MSWI are aggregated to “total energy recovery”. For a more detailed description see Table 22 to Table 25.

	Base case		**Future case**	
	Total energy recovery	Landfill	Total energy recovery	Landfill
Packaging	40%	60%	67%	33%
B&C	20%	80%	45%	55%
E&E	20%	80%	45%	55%
Automotive	20%	80%	45%	55%
Other	20%	80%	45%	55%

Table 17: Assumptions for the distribution of not recycled, available waste to total energy recovery (i.e. industrial energy recovery and MSWI) and landfill.

				Base case			
	Market share	Waste / consumpt. (same year)	Share within avail. waste	Mech. recycling	Total energy recovery	Landfill	Total
Packaging	38,1%	100%	42%	24,0%	30%	46%	100%
B&C	17,6%	47%	9%	11,8%	17%	71%	100%
E&E	7,3%	100%	8%	4,8%	16%	79%	100%
Automotive	7,0%	100%	8%	6,5%	9%	84%	100%
Other	30,0%	100%	33%	1,7%	19%	80%	100%
Total (consumption)	*100,0%*	***91%***		*13%*	*22%*	*65%*	
Total (waste)			**100%**	**13%**	**23%**	**65%**	

Table 18: Resulting figures for the distribution of available waste to recycling, energy recovery and landfill, base case.

				Future case			
	Market share	Waste / consumpt. (same year)	Share within avail. waste	Mech. recycling	Total energy recovery	Landfill	Total
Packaging	38,1%	100%	42%	26,5%	49%	24%	100%
B&C	17,6%	47%	9%	17,8%	38%	44%	100%
E&E	7,3%	100%	8%	7,3%	45%	48%	100%
Automotive	7,0%	100%	8%	9,7%	45%	45%	100%
Other	30,0%	100%	33%	3,0%	45%	52%	100%
Total (consumption)	*100,0%*	***91%***		*15%*	*45%*	*39%*	
Total (waste)			**100%**	**15%**	**46%**	**39%**	

Table 19: Resulting figures for the distribution of available waste to recycling, energy recovery and landfill, future case.

3.4.2 Details of assumptions for waste management

Density of waste materials:

To calculate energy demand and emissions of waste collection processes, also estimated values for the density of the materials collected are taken into account:

Packaging materials in residual waste	
41	PE, PP, PS
25	PET bottles
400	Glass
70	Aluminium
100	Tin plate
60	Paper/cardboard
50	Composite carton
70	Wood
Packaging materials in separate collection	
24	PE, PP, PS
19	PET bottles
280	Glass
40	Aluminium
55	Tin plate
30	Paper/cardboard
25	Composite carton
45	Wood
Other materials (non packaging)	
73	Plastics in residual waste
200	Metals in residual waste
100	plastic pipes in container
400	metal pipes in container
420	concrete and fibrecement pipes
12	EPS insulation
35	mineral wool
150	flooring
200	wood

Table 20: Density values in kg/m3 used in the calculation model.
Source: GUA-database for waste management processes.

Density of other materials is estimated with orientation at the values given above.

Recycling already included in primary production:

If the primary production of a product already includes a certain amount of recycling, then this amount is subtracted from the total flow into the recycling process to avoid double counting of energy demand for recycling and of credits of substituted primary production. If the total flow into recycling is lower than the recycling material already included in the primary production, the resulting “negative credits” represent the additional primary production which is necessary in these cases.[2] Primary production processes that already include recycling

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[2] In this calculation model, a product cannot “borrow” recycling material from other product segments. Primary production can only make use of recycling material which comes from recycling of the same product in this model.

are white glass (62,5 %), tin plate (12,2 %), corrugated board (75,9 %), and cardboard and packaging paper (24,8 %).

Example packaging paper: For carrier bags, a recycling rate of 40 % is assumed. As the primary production already includes 24,8 % recycled paper (and the related use of fuels, etc.), only the additional recycling of 40 % − 24,8 % = 15,2 % is considered in the waste management phase.

Example white glass: For “other rigid packaging” (many small volumes), again a recycling rate of 40 % is assumed. At the same time, the primary production data of white glass is based on a recycling rate of 62,5 %. The difference, 40 % − 62,5 % = −22,5 %, represent the additional primary production (and its fuel demand, etc.) which is necessary, if only 40 % of white glass can be separately collected in waste management instead of 62,5 %.

The calculations are based on "clean" materials (without adhering dirt and moisture). In the processes for energy recovery, these masses are combined with the gross heating values of the clean materials. This calculation produces an error by neglecting the energy needed to vaporize the water in/on the waste. The respective energy is only about 2 % of the heating value of the dry material, therefore this error is neglected.

Energy recovery and MSWI:

Energy recovery beside MSWI is called "industrial energy recovery” and stands for the use of “refuse derived fuel” in power plants, cement kilns, fluidised bed combustion processes and blast furnaces. All of these processes substitute mainly the use of coal, partly heavy fuel oil and in a few cases gas.

In this calculation model, the following share of fuels is *assumed* for this kind of substitution (this assumption is supposed to represent average Western European conditions):

60 % substitution of coal

30 % substitution of heavy fuel oil

10 % substitution of gas

Efficiency of utilisation is *assumed* to be 80 % for waste fuels instead of 90 % for standard fuels.

For MSWI it is *assumed* that 70 % of the plants produce electricity alone (20 % net-efficiency) and 30 % produce electricity and steam for heating (net-efficiency: 12 % electricity and 68 % steam). Plants producing electricity alone are assumed to substitute average European electricity production. For plants producing electricity and steam, the substitution was assumed in the same way as for industrial energy recovery.

For all combustible residues from sorting and recycling processes it was assumed that they are used in a fluidised bed combustion process, as this is the most appropriate process for all kinds of combustible residues.

Gross calorific values and fossile carbon content:

	H_u	H_o	fossile C-content
PE	43,7	46,5	86%
PET	42,2	44,9	63%
PP	44,1	46,9	86%
PS	45,5	48,4	92%
EPS	45,6	48,5	92%
PVC	27,1	28,8	38%
PUR	26,0	27,6	65%
Rubber	16,0	17,0	55%
Linoleum	11,7	12,5	0%
Leather	18,4	19,5	0%
Paper	15,4	16,4	0%
Wood	15,3	16,3	0%

Table 21: Net calorific values, gross calorific values and fossil carbon content of clean and dry waste materials used in the calculation model.

CH_4 emissions from landfills

CH_4 emissions in grams per tonne material in landfill within 50 years (Source: Technical University of Vienna, institute for waste management, written information):

Wood: 185.600 g/t, paper: 132.100 g/t, linoleum: 92.800 g/t (estimated; see chapter 4.3.2.4)

The following tables show **further detailed data** used to calculate the effects of waste management for the case studies analysed.

Recycling rates base case	Total plastics recycling	LDPE	HDPE	PP	PVC	PS	EPS	PET	**PE-X**, PMMA	**ABS**/SAN & oth. thermopl.	PUR	Other thermosets	Steel	Zinc coated iron	Cast iron	Tin plate	Aluminium	Copper	Glass	Fibrecement	Stoneware	Concrete	Corrug. Board / Cardboard	Paper / fibre cast	Paperbased composites	**Wood**, textile, etc.	Other	Stays in the ground	Plastics	Metals, Glass, Minerals	Paper	Shredder	Residual Waste	Landfill	En. Recov. - MSWI	En. Recov. - industrial
small packaging		0%	0%	0%	0%	0%		0%								5%	0%		5%				5%	5%	0%	0%			30%	20%	10%	0%	100%	60%	35%	5%
beverage bottles								40%								50%	30%		60%						0%				10%	10%	-	0%	100%	60%	35%	5%
other bottles		20%	20%	20%	20%	20%		20%								50%	10%		40%						0%				20%	10%	-	0%	100%	60%	35%	5%
other rigid packaging	**24,0%**		20%	20%	20%	20%	20%									50%	10%		40%				40%	40%	0%	0%			20%	10%	10%	0%	100%	60%	35%	5%
shrink and stretch films		80%														50%							70%	70%	0%	0%			5%	5%	5%	0%	100%	60%	35%	5%
carrier bags		20%																						40%					20%	-	10%	0%	100%	60%	35%	5%
other flexible packaging		10%		10%	10%	10%										50%	10%		40%				40%	40%	0%	0%			30%	10%	10%	0%	100%	60%	35%	5%
big drain and sewer pipes	**% of market input 4,6%** **% of available waste 12%**		0%	0%	0%										0%					0%	0%	0%						100%	-	-	-	-	-	-	-	-
small drain and sewer p.			10%	10%	10%								20%		20%		20%			0%	0%							50%	10%	10%	-	0%	100%	80%	18%	2%
big drinking water pipes			0%		0%				0%						0%			0%		0%								100%	-	-	-	-	-	-	-	-
small drinking water pipes			10%		10%				10%				20%	20%				30%										50%	10%	10%	-	0%	100%	80%	18%	2%
agricultural pipes			10%	10%	10%								20%		20%		20%			0%								50%	10%	10%	-	0%	100%	80%	18%	2%
conduit pipes			0%		0%								0%															20%	10%	10%	-	0%	100%	80%	18%	2%
gas pipes			70%										60%	60%														50%	10%	10%	-	0%	100%	80%	18%	2%
heating and plumbing p.				10%					10%				20%		20%			30%										20%	10%	10%	-	0%	100%	80%	18%	2%
industry pipes			10%	10%	10%				10%	10%			20%		20%		20%	30%									(Mineral wool)	20%	10%	10%	-	0%	100%	80%	18%	2%
insulation	**13,6%** **17,3%**					0%	0%				0%								0%							(Linoleum)	0%	40%	-	-	-	10%	90%	81%	17%	2%
flooring					10%	(XPS)													(Foamglass)							0%			10%	-	-	0%	100%	80%	18%	2%
windows					17%												30%									0%			5%	5%	-	0%	100%	80%	18%	2%
housing	**6%**			0%		0%				15%			30%				10%		(Mineral wool)							0%	0%		5%	5%	-	30%	70%	83%	15%	2%
insulation in refrig.						(HIPS)					0%								0%								(rubber)		10%	-	-	30%	70%	83%	15%	2%
under the hood	**14%**		5%	5%					(PMMA)	5%	(PA-GF)		80%				20%												5%	10%	-	100%	0%	90%	8%	2%
exterior and cockpit				40%					40%	40%			80%				20%		0%								(rubber)		5%	10%	-	100%	0%	90%	8%	2%
other automotive parts				0%						0%	0%		80%				20%		0%								20%		5%	10%	-	100%	0%	90%	8%	2%
keep fresh boxes	**16%**			5%									15%				15%		15%										10%	10%	-	0%	100%	80%	18%	2%
buckets				5%										15%															5%	5%	-	0%	100%	80%	18%	2%
waste bins			60%											70%															5%	5%	-	0%	100%	80%	18%	2%
garden furniture	**5%**			5%									60%				15%									0%	(latex)		5%	5%	-	30%	70%	83%	15%	2%
matresses											5%		5%														0%		10%	10%	-	30%	70%	83%	15%	2%
syringes	**0%**			0%															0%										-	-	-	0%	100%	80%	18%	2%
infusion containers					0%														0%							(leather)	(rubber)		-	-	-	0%	100%	80%	18%	2%
soles	**0%**				0%						0%															0%	0%		-	-	-	0%	100%	80%	18%	2%

Table 22: Assumptions for mechanical recycling rates in the analysed case studies – "base case"

	Combustible waste			**Other materials**		
	Packaging	**Non-packaging**		**Packaging**	**Non-packaging**	
	Residual waste	Shredder residues	Residual waste	Residual waste	Shredder residues	Residual waste
Assumptions for residual waste and shredder residues:						
Landfill	**60%**	90%	**80%**	70%	100%	80%
En. Recov. - MSWI	35%	8%	18%	30%	0%	20%
En. Recov. - industrial	5%	2%	2%			
Total energy recovery	***40%***	*10%*	***20%***	*30%*	*0%*	*20%*
Total	100%	100%	100%	100%	100%	100%
Assumptions for sorting residues:						
Landfill				100%	100%	
En. Recov. - industrial	100%	100%				

Table 23: Assumptions for energy recovery and landfill shares in the analysed case studies – "base case"

Recycling rates future case	**Total plastics recycling**	LDPE	HDPE	PP	PVC	PS	EPS	PET	**PE-X**, PMMA	**ABS**/SAN & oth. thermopl.	PUR	Other thermosets
small packaging		0%	0%	0%	0%	0%		0%				
beverage bottles								55%				
other bottles		22%	22%	22%	22%	22%		22%				
other rigid packaging	**26,5%**		22%	22%	22%	22%	22%					
shrink and stretch films		80%										
carrier bags		22%										
other flexible packaging		10%		10%	10%	10%						
big drain and sewer pipes	**6%** **16%**		0%	0%	0%							
small drain and sewer p.			15%	15%	15%							
big drinking water pipes			0%		0%				0%			
small drinking water pipes	**% of market input** **% of available waste**		15%		15%				15%			
agricultural pipes			15%	15%	15%							
conduit pipes			0%		0%							
gas pipes			70%									
heating and plumbing p.				15%					15%			
industry pipes			15%	15%	15%				15%	15%		
insulation	**22,0%** **27,8%**					0%	0%				0%	
flooring					18%	(XPS)						
windows					26%							
housing	**11%**			5%		5%				20%		
insulation in refrig.						(HIPS)					0%	
under the hood	**21%**		10%	10%					(PMMA)	10%	(PA-GF)	
exterior and cockpit				50%					50%	50%		
other automotive parts				0%						0%	10%	
keep fresh boxes	**20%**			5%								
buckets				15%								
waste bins			70%									
garden furniture	**20%**			20%								
matresses											20%	
syringes	**0%**			0%								
infusion containers					0%							
soles	**0%**				0%						0%	

Recycling rates future case	Steel	Zinc coated iron	Cast iron	Tin plate	Aluminium	Copper	Glass	Fibrecement	Stoneware	Concrete	Corrug. Board / Cardboard	Paper / fibre cast	Paperbased composites	**Wood**, textile, etc.	Other
small packaging				10%	0%		10%				10%	10%	0%	0%	
beverage bottles				60%	40%		70%						0%		
other bottles				60%	20%		50%						0%		
other rigid packaging				60%	20%		50%				50%	50%	0%	0%	
shrink and stretch films				60%							80%	80%	0%	0%	
carrier bags												50%			
other flexible packaging				60%	20%		50%				50%	50%	0%	0%	
big drain and sewer pipes			0%					0%	0%	0%					
small drain and sewer p.	25%		25%		25%			0%	0%						
big drinking water pipes			0%			0%		0%							
small drinking water pipes	25%	25%				40%									
agricultural pipes	25%		25%		25%			0%							
conduit pipes	0%														
gas pipes	80%	80%													
heating and plumbing p.	25%		25%			40%									
industry pipes	25%		25%		25%	40%									(Mineral wool)
insulation							0%							(Linoleum)	0%
flooring							(Foamglass)							0%	
windows					50%									0%	
housing	60%				30%		(Mineral wool)							0%	0%
insulation in refrig.							0%								(rubber)
under the hood	90%				40%										
exterior and cockpit	90%				40%		20%								(rubber)
other automotive parts	90%				40%		20%								40%
keep fresh boxes	30%				30%		30%								
buckets		30%													
waste bins		80%													
garden furniture	80%				40%									0%	(latex)
matresses	20%														0%
syringes							0%								
infusion containers							0%							(leather)	(rubber)
soles														0%	0%

Recycling rates future case	**Stays in the ground**	**Plastics**	**Metals, Glass, Minerals**	**Paper**	**Shredder**	**Residual Waste**	Landfill	En. Recov. - MSWI	En. Recov. - industrial
small packaging		30%	20%	10%	0%	100%	33%	33%	33%
beverage bottles		10%	10%	-	0%	100%	33%	33%	33%
other bottles		20%	10%	-	0%	100%	33%	33%	33%
other rigid packaging		20%	10%	10%	0%	100%	33%	33%	33%
shrink and stretch films		5%	5%	5%	0%	100%	33%	33%	33%
carrier bags		20%	-	10%	0%	100%	33%	33%	33%
other flexible packaging		30%	10%	10%	0%	100%	33%	33%	33%
big drain and sewer pipes	100%	-	-	-	-	-	-	-	-
small drain and sewer p.	50%	10%	10%	-	0%	100%	55%	30%	15%
big drinking water pipes	100%	-	-	-	-	-	-	-	-
small drinking water pipes	50%	10%	10%	-	0%	100%	55%	30%	15%
agricultural pipes	50%	10%	10%	-	0%	100%	55%	30%	15%
conduit pipes	20%	10%	10%	-	0%	100%	55%	30%	15%
gas pipes	50%	10%	10%	-	0%	100%	55%	30%	15%
heating and plumbing p.	20%	10%	10%	-	0%	100%	55%	30%	15%
industry pipes	20%	10%	10%	-	0%	100%	55%	30%	15%
insulation	40%	-	-	-	70%	30%	52%	23%	26%
flooring		10%	-	-	0%	100%	55%	30%	15%
windows		5%	5%	-	0%	100%	55%	30%	15%
housing		5%	5%	-	70%	30%	52%	23%	26%
insulation in refrig.		10%	-	-	70%	30%	52%	23%	26%
under the hood		5%	10%	-	100%	0%	50%	20%	30%
exterior and cockpit		5%	10%	-	100%	0%	50%	20%	30%
other automotive parts		5%	10%	-	100%	0%	50%	20%	30%
keep fresh boxes		10%	10%	-	0%	100%	55%	30%	15%
buckets		5%	5%	-	0%	100%	55%	30%	15%
waste bins		5%	5%	-	0%	100%	55%	30%	15%
garden furniture		5%	5%	-	70%	30%	52%	23%	26%
matresses		10%	10%	-	70%	30%	52%	23%	26%
syringes		-	-	-	0%	100%	55%	30%	15%
infusion containers		-	-	-	0%	100%	55%	30%	15%
soles		-	-	-	0%	100%	55%	30%	15%

Table 24: Assumptions for mechanical recycling rates in the analysed case studies – "future case"

	Combustible waste			**Other materials**		
	Packaging	**Non-packaging**		**Packaging**	**Non-packaging**	
	Residual waste	Shredder residues	Residual waste	Residual waste	Shredder residues	Residual waste
Assumptions for residual waste and shredder residues:						
Landfill	**33%**	50%	**55%**	50%	100%	70%
En. Recov. - MSWI	33%	20%	30%	50%	0%	30%
En. Recov. - industrial	33%	30%	15%			
Total energy recovery	***67%***	*50%*	***45%***	*50%*	*0%*	*30%*
Total	100%	100%	100%	100%	100%	100%
Assumptions for sorting residues:						
Landfill				100%	100%	
En. Recov. - MSWI						
En. Recov. - industrial	100%	100%				

Table 25: Assumptions for energy recovery and landfill shares in the analysed case studies – "future case"

	Gross calorific value [MJ/kg]	Fossile carbon content	Density in collection [kg/m3]	Residual waste collection	Bulky refuse collection	Domestic/commercial separate collection (1,1 m3 cont.)	Commercial waste collection (8 m3 cont.)	Sorting Plastics	Sorting Paper	Shredder plastics	Shredder Metals	Aluminium recycling	Tin plate recycling	Steel / cast iron recycling	copper recycling	Paper packaging recycling (corr. cardb.)	Paper packaging recycling (cardb.)	Mechanical Recycling Plastics 1 (wash/granulate)	Mechanical Recycling Plastics 2 (PET)	Mechanical Recycling Plastics 3 (fine grinding)	Industrial energy recovery including fuel production	MSWI
Plastic Packaging																						
small packaging PS+PP	48	89%	41	1,00		0,00		0,00										0,00			0,05	0,35
beverage bottles PET	42	63%	25	0,56		0,44		0,44											0,40		0,11	0,19
other bottles HDPE	46	86%	33	0,75		0,25		0,25										0,20			0,11	0,26
other rigid packaging HDPE+PS	47	89%	25	0,75		0,25		0,25										0,20			0,11	0,26
shrink and stretch films LDPE	46	86%	41	0,16		0,84		0,84										0,80			0,13	0,06
carrier bags LDPE	46	86%	41	0,75		0,25		0,25										0,20			0,11	0,26
other flexible packaging LDPE	46	86%	41	0,86		0,14		0,14										0,10			0,10	0,30
Other Packaging																						
Tin plate low recycling			100	0,94		0,06					0,06		-0,10									
Tin plate high recycling			100	0,44		0,56					0,56		0,35									
Aluminium no recycling			70	1,00		0,00					0,00	0,00										
Aluminium high recycling			70	0,67		0,33					0,33	0,30										
Aluminium medium recycling			70	0,89		0,11					0,11	0,10										
Glass low recycling			400	0,94		0,06																
Glass high recycling			400	0,33		0,67																
Glass medium recycling			400	0,56		0,44																
Corrug. Board / Cardboard low rec.	16		60	0,94		0,06			0,06							-0,13	-0,13				0,36	0,33
Corrug. Board / Cardboard med. rec.	16		60	0,56		0,44			0,44							0,04	0,04				0,39	0,19
Corrug. Board / Cardboard high rec.	16		60	0,26			0,74		0,74							0,19	0,19				0,39	0,09
Paper / fibre cast low recycling	16		60	0,94		0,06			0,06							-0,06	-0,06				0,21	0,33
Paper / fibre cast medium recycling	16		60	0,56		0,44			0,44							0,12	0,12				0,25	0,19
Paper / fibre cast high recycling	16		60	0,26			0,74		0,74							0,27	0,27				0,24	0,09
Paperbased composites	22	17%	50	**1,00**																	0,05	0,35
Wood, textile, etc.	15		70				1,00														0,05	0,35
Plastic Pipes - data per kg available waste																						
small drain and sewer p. HDPE low re	44	86%	100	0,89		0,11		0,11		0,10								0,10			0,04	0,16
conduit pipes HDPE zero recycling	44	86%	100	**1,00**		0,00															0,02	0,18
gas pipes HDPE high recycling	44	86%	100	0,22		0,78		0,78		0,70								0,70			0,15	0,04
small drain and sewer p. PP	47	86%	100	0,89		0,11		0,11		0,10								0,10			0,04	0,16
small drain and sewer p. PVC	29	38%	100	0,89		0,11		0,11		0,00										0,10	0,03	0,16
conduit pipes PVC zero recycling	29	38%	100	**1,00**		0,00															0,02	0,18
Other Pipes - data per kg available waste																						
small drain and sewer p. Steel low recycling			400	0,78		0,22					0,22			0,20								
conduit pipes Steel zero recycling			400	**1,00**																		
gas pipes Steel high recycling			400	0,33		0,67					0,67			0,20								
small drain and sewer p. Aluminium			400	0,78		0,22					0,22	0,22										
small drinking water pipes Copper			400	0,67		0,33					0,33				0,33							
small drain and sewer p. Fibrecement			420	**1,00**																		

Table 26: Material specific data and distribution of 1 kg of waste within the waste processes considered, listed for products (materials) within case studies (part 1). Negative values in the columns of recycling processes represent additional primary production needed instead of recycling (see "recycling already included in primary production" explained above.

	Gross calorific value [MJ/kg]	Fossile carbon content	Density in collection [kg/m3]	Residual waste collection	Bulky refuse collection	Domestic/commercial separate collection (1,1 m3 cont.)	Commercial waste collection (8 m3 cont.)	Sorting Plastics	Sorting Paper	Shredder plastics	Shredder Metals	Aluminium recycling	Tin plate recycling	Steel / cast iron recycling	copper recycling	Paper packaging recycling (corr. cardb.)	Paper packaging recycling (cardb.)	Mechanical Recycling Plastics 1 (wash/granulate)	Mechanical Recycling Plastics 2 (PET)	Mechanical Recycling Plastics 3 (fine grinding)	Industrial energy recovery including fuel production	MSWI
Plastics in B&C: non-pipes																						
insulation EPS	48	92%	12	**1,00**						0,19											0,02	0,17
flooring PVC	14	19%	150			0,11	0,89			0,11										0,05	0,03	0,16
windows PVC	22	29%	150			0,18	0,82			0,14	0,04			0,10						0,08	0,08	0,15
Other materials in B&C: non-pipes																						
insulation (Mineral wool)			35				**1,00**															
flooring (Linoleum)	12	0%	150				**1,00**														0,02	0,18
windows Aluminium			200			0,32	0,68				0,32	0,30										
windows wood	16		150				**1,00**														0,02	0,18
Plastics in E&E																						
housing PP	47	86%	73		1,00	0,00														0,00	0,02	0,15
housing PS	48	92%	73		1,00	0,00														0,00	0,02	0,15
housing ABS	48	92%	73		0,84	0,16														0,15	0,03	0,13
insulation in refrig. PUR	28	65%	73		1,00	0,00														0,00	0,02	0,15
Other materials in E&E																						
housing Steel			200		0,68	0,32					0,32			0,30								
housing Aluminium			200		0,89	0,11					0,11	0,10										
housing wood	16	0%	73		**1,00**																0,02	0,15
housing (rubber)	17	55%	73		**1,00**																0,02	0,15
Plastics in the automotive sector																						
under the hood HDPE	46	86%	73			0,05	0,95			0,05								0,05			0,03	0,08
under the hood PP	47	86%	73			0,05	0,95			0,05								0,05			0,03	0,08
under the hood PA-GF	46	86%	73			0,05	0,95			0,05								0,05			0,03	0,08
exterior and cockpit PP	47	86%	73			0,42	0,58			0,42								0,40			0,07	0,05
exterior and cockpit PMMA	46	86%	73			0,42	0,58			0,42								0,40			0,07	0,05
exterior and cockpit ABS	46	86%	73			0,42	0,58			0,42								0,40			0,07	0,05
other automotive parts other	47	86%	73				**1,00**														0,02	0,08
other automotive parts PUR	28	65%	73			0,00	1,00			0,00										0,00	0,02	0,08
Other materials in the automotive sector																						
under the hood Steel			200				0,89				0,89			0,80								
under the hood Aluminium			200			0,22	0,78				0,22	0,20										
exterior and cockpit Glass			400			0,00	1,00															
other automotive parts Rubber	17	55%	73			0,21	0,79			0,21										0,20	0,04	0,06

Table 27: Material specific data and distribution of 1 kg of waste within the waste processes considered, listed for products (materials) within case studies (part 2) Negative values in the columns of recycling processes represent additional primary production needed instead of recycling (see “recycling already included in primary production” explained above.

	Gross calorific value [MJ/kg]	Fossile carbon content	Density in collection [kg/m3]	Residual waste collection	Bulky refuse collection	Domestic/commercial separate collection (1,1 m3 cont.)	Commercial waste collection (8 m3 cont.)	Sorting Plastics	Sorting Paper	Shredder plastics	Shredder Metals	Aluminium recycling	Tin plate recycling	Steel / cast iron recycling	copper recycling	Paper packaging recycling (corr. cardb.)	Paper packaging recycling (cardb.)	Mechanical Recycling Plastics 1 (wash/granulate)	Mechanical Recycling Plastics 2 (PET)	Mechanical Recycling Plastics 3 (fine grinding)	Industrial energy recovery including fuel production	MSWI
Housewares made of plastics																						
keep fresh boxes PP	47	86%	41	0,94		0,06		0,06										0,05			0,03	0,17
buckets PP	47	86%	41	0,95		0,05		0,05										0,05			0,03	0,17
waste bins HDPE	46	86%	73		0,63		0,37			0,63								0,60			0,10	0,07
Housewares made of other materials																						
keep fresh boxes Steel			100	0,83		0,17					0,17			0,15								
keep fresh boxes Aluminium			100	0,83		0,17					0,17	0,15										
keep fresh boxes Glass			400	0,83		0,17																
waste bins Zinc coated iron			200		0,74		0,26							0,70								
Furniture made of plastics																						
garden furniture PP	47	86%	73		0,95		0,05			0,05								0,05			0,03	0,14
matresses PUR	28	65%	35		0,94		0,06	0,06												0,05	0,03	0,14
Furniture made of other materials																						
garden furniture Steel			200		0,37		0,63				0,63			0,60								
garden furniture Aluminium			200		0,84		0,16				0,16	0,15										
garden furniture wood	16	0%	73		**1,00**																0,02	0,15
matresses Steel			16		0,94		0,06				0,06			0,05								
matresses latex	17	0%	75		**1,00**																0,02	0,15
Plastics for medicine																						
syringes PP	47	86%	41	**1,00**																	0,02	0,18
infusion containers PVC	29	38%	41	**1,00**																	0,02	0,18
Other materials for medicine																						
syringes Glass			400			**1,00**																
Plastics for footware																						
soles PVC	29	38%	73	**1,00**																	0,02	0,18
soles PUR	28	65%	73	**1,00**																	0,02	0,18
Other materials for footware																						
soles leather	20		73	**1,00**																	0,02	0,18
soles rubber	17	55%	73	**1,00**																	0,02	0,18

Table 28: Material specific data and distribution of 1 kg of waste to the waste processes considered, listed for products (materials) within case studies (part 3). Negative values in the columns of recycling processes represent additional primary production needed instead of recycling (see “recycling already included in primary production” explained above.

	Unit	Residual waste collection	Bulky refuse collection	Domestic/commercial separate collection (1,1 m^3 cont.)	Commercial waste collection (8 m^3 cont.)	Sorting Plastics	Sorting Paper	Shredder plastics	Shredder Metals	Aluminium recycling	Tin plate recycling	Steel / cast iron recycling	copper recycling	Paper packaging recycling (corr. cardb.)	Paper packaging recycling (cardb.)	Mechanical Recycling Plastics 1 (wash/granulate)	Mechanical Recycling Plastics 2 (PET)	Mechanical Recycling Plastics 3 (fine grinding)	Industrial energy recovery including fuel production	MSWI
Input																				
Data related to input of		**1m3**	**1m3**	**1m3**	**1m3**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 t**	**1 MJ**	**1MJ**
Fuels																				
electricity	kWh					50	15	32	40	342	783	693	576	355	96	800	168	103	0,002	
steam	MJ													2890	29					
heavy fuel oil	kg									23				14	30		0			
gas	m3									93	6	5	4	105	191		20			
petrol/diesel	kg	0,71	1,18	0,92	1,68	3	1	1						1	1		0			
fuel oil extra light	kg													4	2	16	0			
wood	kg														32					
Output																				
Amount	t									0,90	0,84	0,95	0,95	0,95	0,95	0,90	0,90	0,95		
Substitution factor										0,90	1,00	1,00	0,90	0,60	0,90	0,90	0,90	0,90	0,889	
Waste for energy recovery	t													0,05	0,05	0,10	0,10	0,05		
Substituted electricity	kWh																			-0,039
Substitition of coal	kg																		-0,018	-0,005
Subst. of heavy fuel oil	kg																		-0,006	-0,002
Substitition of gas	m3																		-0,002	-0,001

Table 29: Data regarding specific fuel demand, products and residues of the waste processes considered as well as substitution factors regarding the amount of substituted primary production by the products of recycling processes.

Sources of data:

Fuel demand of aluminium recycling, tin plate recycling, steel / cast iron recycling, paper packaging recycling (product: middle layer of corrugated cardboard), paper packaging recycling (product: cardboard), mechanical recycling of PET bottles has been taken from ETH & EMPA [1996].

Fuel demand of copper recycling has been estimated by using the fusion heat of iron and copper.

Losses / residues of recycling processes and substitution factors are estimated.

Other data comes from the GUA database for waste processes, based on data from waste collectors, recycling and disposal plants.

4 CASE STUDIES

4.1 Packaging

4.1.1 Data for all case studies in the sector

4.1.1.1 Market share of plastic products

Not substitutable plastic packaging: 2,2 % of total plastic packaging; see chapter 2.2.1.

Small packaging (smaller than 50 ml, smaller than 300 cm^2, edge length beyond 5 cm): The proportion of substitutable small packaging in the total plastic packaging market has been calculated by using the total amount of plastic packaging in Germany in the year 2000 [GVM, 2002], the amount of substitutable small packaging in Germany in 1997 [GVM 1998] and the increase in domestic plastic packaging from 1997 to 2000 [GVM, 2002b]. The result shows that 6,43 % of total plastic packaging in Germany is small plastic packaging, which is used as an estimate for Western Europe.

Beverage packaging: Market data from AJI-Europe collected for PlasticsEurope for 2001 show that 12 % of the total plastic packaging market are beverage bottles (1.540 kt PET bottles and 80 kt PVC bottles in food sector).

Other bottles: The total mass of plastic bottles in 2001 (4.143 kt) was reduced by 10 % (estimated) due to inclusion of non-bottle injection moulding and small packaging bottles in total mass of plastics bottles. Subtraction of beverage bottles leads to the total amount of “other bottles”, which are 15,6 % of the total market of plastic packaging.

The remaining market share of other plastic packaging applications (= total market without not substitutable packaging, small packaging, beverage packaging and other bottles) was split into shares of **other rigid packaging, shrink and stretch films, carrier-bags** and **other flexible packaging** by using the relations of these sectors derived from aggregation of data given in the study of GVM [2004] for the German market in 2002.

4.1.1.2 Polymers considered in the case studies

Small packaging: The split of small packaging into polymers was directly taken from GVM [1998] (polymers used in Germany for small packaging in 1997, used as an estimate for Western Europe).

Beverage packaging: Data from AJI Europe show that only 5 % of beverage bottles are made of PVC. Therefore the calculations in this study cover only PET beverage bottles. The difference to PVC bottles for 5 % of the total amount of beverage bottles is neglected.

Shrink & stretch films and carrier-bags are assumed to be LDPE. The difference between LLDPE and LDPE for stretch films is neglected.

Other bottles, other rigid packaging and other flexible packaging: Data on the polymers used was derived from aggregation of data given in GVM [2004] (polymer split in Germany, used as an estimate for Western Europe).

4.1.1.3 Mass ratios

Small packaging: The mass ratios in case of substitution of small plastic packaging by other materials were directly taken from GVM [1998], where a detailed substitution model for small packaging in Germany was elaborated for 1997, split into 33 different sectors of the economy.

Beverage packaging: see chapter 4.1.2.

The mass ratios for **all other packaging categories** were derived from aggregation of data given in GVM [2004]. These data represent mass ratios for the German market in 2002. The aggregation was worked out by GVM and GUA in co-operation. The original substitution model of GVM distinguishes between 32 different categories of domestic and commercial packaging and between 69 different materials, and its mass ratios are based on a large database containing about 16.300 data sets of packaging materials, sizes, volumes, and masses.

Various steel, thin sheet and tin plate packaging were aggregated into one group (56 % steel and thin sheet packaging, 44 % tin plate packaging). Wood, cork, textiles and cellophane were also aggregated (60 % wood and cork, 33 % textiles, 7 % cellophane) and treated as wood packaging (very small influence on the result).

Table of mass ratios	**Market share plastics**	**Plastics total**	LDPE	HDPE	PP	PVC	PS	EPS	PET	**Altern. mat. - Total**	Steel / tin plate	Aluminium	Glass	Corrug. Board / Cardboard	Paper / fibre cast	Paperbased composites	**Wood**, textile, etc.
small packaging	2,45%	**1,00**	0,18	0,04	0,31	0,10	0,28		0,08	3,35	0,33	0,15	1,45	0,24	0,72	0,24	0,21
beverage bottles	4,57%	**0,83**							0,83	8,70	0,08	0,03	8,52			0,06	
other bottles	5,95%	**1,00**	0,01	0,60	0,16	0,01			0,23	5,24	0,92	0,02	4,25			0,06	
other rigid packaging	11,18%	**1,00**		0,32	0,35	0,01	0,25	0,08		1,73	0,37	0,09	0,14	0,22	0,26	0,29	0,35
shrink and stretch films	5,85%	**1,00**	1,00							5,98	0,77			3,81	1,03	0,04	0,34
carrier-bags	1,13%	**1,00**	1,00							2,64					2,64		
other flexible packaging	6,13%	**1,00**	0,51		0,41	0,06	0,02			2,23	0,33	0,00	0,05	0,05	0,74	0,64	0,42

Table 30: Mass ratios for the substitution of plastic packaging used in this study

4.1.1.4 Energy and emissions of production phase

Data on energy demand and emissions for the production of plastic packaging are taken from the inventories published by PlasticsEurope. For alternative packaging materials most data are taken from ETH & EMPA [1996].

Data for LDPE bottles (in “other bottles”) are produced by using data for LDPE granulate and bottle processing energy for HDPE bottles. In the same way, data for PP film (in “other flexible packaging”) are produced by using data for PP granulate and film processing energy for LDPE film.

Steel and thin sheet packaging: Inventories of steel products strongly depend on the share of alloying metals used. The energy demand to produce unalloyed steel is about 19 MJ/kg, steel with 18 % Cr and 8 % Ni needs 68 MJ/kg to be produced. Straps for pallets are the dominating product within steel and thin sheet packaging. Information about their steel quality was not available. Therefore the inventory for tin plate packaging (36 MJ/kg, equivalent to

"35 %" of the interval 19 (0 %) – 68 (100 %) MJ/kg) is also used as an estimate for steel and thin sheet packaging.

Data for corrugated board is taken from the latest inventory published by FEFCO, the European Federation of Corrugated Board Manufacturers [FEFCO 2003]. The inventory presents data for Kraftliner, Semi-chemical Fluting, Testliner and Wellenstoff. For this study, the data is aggregated according to the mix of these components in the Western European corrugated board production. The total fuel demand is finally expanded by the energy needed to produce and deliver the fuels.

The "category paper & cardboard" is a mix of 65 % paper and 35 % cardboard. Data for cardboard is a mix of grey cardboard (50 %) and primary cardboard (50 %). Data for packaging paper was put together from craft paper (with bleaching, without bleaching, coated on one side; 25 % each) and Swiss craft (25 %).

Beverage carton is a mix of 80 % liquid packaging board [ETH & EMPA 1996] and 20 % LDPE film.

No specific data exists for wood packaging. Energy and emissions for the production of wood packaging are therefore estimated by using half the energy needed to produce 1 kg of a wooden window frame [Umweltbundesamt Berlin, 1998]. The values used for wood packaging have only a very small influence on the result.

Data for glass production include an input of 62,5 % glass waste, the production of tin plate an input of 12,2 % metal scrap, the production of corrugated board an input of 75,9 % waste paper/cardboard and the production of packaging paper and cardboard an input of 24,8 % waste paper/cardboard. In the calculations within waste management, these amounts are subtracted from (partly higher) recycling rates to avoid double counting of energy demand for recycling and of substituted primary production.

The values listed below include feedstock energy and precombustion energy demand.

Material	Product	Total energy demand	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	other
		MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg
LDPE	film	**91,81**	5,29	33,11	43,59	1,43	5,71	0,12	2,44	0,12
HDPE	bottles	**99,80**	11,18	50,46	26,90	1,21	9,66	0,11	0,05	0,23
PP	injection moulding	**118,84**	12,58	45,74	48,79	0,81	9,82	0,07	0,86	0,19
PVC	UPVC film	**66,25**	6,35	19,32	29,83	0,87	7,85	0,69	0,21	1,13
PS	high impact	**91,81**	2,05	35,54	52,40	0,06	1,87	0,11	0,01	-0,24
PET	bottles	**101,44**	17,09	44,80	27,23	0,48	10,86	0,26	0,03	0,69
PET	film	**109,19**	14,88	44,02	38,14	0,61	8,75	1,64	0,05	1,11
Tin plate	packaging	**35,79**	22,61	4,10	5,07	0,34	2,42	1,01	0,24	0,00
Aluminium	film	**193,27**	30,79	59,28	17,59	48,10	35,18	2,06	0,27	0,00
Glass white	packaging	**12,74**	0,93	8,34	0,57	0,59	2,18	0,12	0,00	0,00
Corrugated board	packaging	**19,45**	0,81	1,08	8,53	0,17	0,82	0,73	7,31	0,00
Paper, cardboard	packaging	**44,79**	0,91	5,41	7,67	2,10	5,60	0,30	22,80	0,00
Beverage carton	packaging	**55,80**	1,32	9,89	9,02	2,81	6,30	0,05	26,38	0,02
Wood	packaging	**17,67**	2,04	0,11	0,50	0,28	2,95	1,57	10,09	0,12

Material	Product	CO_2	CH_4	N_2O
		mg/kg	mg/kg	mg/kg
LDPE	film	1.933.819	8.080	0,1
HDPE	bottles	2.952.299	8.305	0,5
PP	injection moulding	4.013.497	19.990	0,1
PVC	UPVC film	2.256.381	10.118	0,2
PS	high impact	2.737.168	9.247	0,1
PET	bottles	4.272.204	14.507	0,2
PET	film	4.886.655	22.557	0,2
Tin plate	packaging	2.970.000	10.800	9,6
Aluminium	film	8.220.000	18.000	45,7
Glass white	packaging	748.000	781	2,0
Corrugated board	packaging	634.511	2.628	14,5
Paper, cardboard	packaging	867.450	1.800	15,7
Beverage carton	packaging	651.564	1.971	6,1
Wood	packaging	315.595	607	0,0

Table 31: Energy demand and emissions of the production phase of packaging used in this calculation model.

4.1.1.5 Energy and emissions of use phase

Potential effects in the use phase of *packaging in general* are saved food losses due to the use of packaging (compared to distribution of goods without packaging). In this study it is assumed that 70 % of all food packaging (plastics and other materials) prevent the loss of 20 % of the food packed.

For further calculations, the following data is used:

- Average food consumption per person and week: 11 kg [Incpen 1996].
- Average energy consumption to produce and deliver 1 kg of food: 30 MJ/kg [Incpen 1996].
- Approximately 50 % of goods is packed in plastic packaging [PlasticsEurope 2001b]; for food, the same share is assumed.
- Population in Western Europe: 392 Mill inhabitants (2002).
- Total food packaging in Western Europe in 2001: 7.850 kt [AJI-Europe, 2003].

The data listed lead to the result that a certain plastic packaging application, which prevents the loss of 20 % of the food packed, saves about 125 MJ per kg plastic packaging (energy needed to replace the food losses). This is about 30 % more energy than needed to produce average plastic packaging. Other packaging materials of course lead to similar benefits in the use phase.

In addition to the effect described above for *all* packaging materials, it is assumed in this study that 20 % of the total food packaging made of plastics lead to an *extra 5 %* saving of food losses compared to a hypothetical scenario, where all plastic food packaging has been substituted by other materials. This extra saving is assumed because plastic food packaging often allows delivering food in portions better adapted to the need of the consumer and helps to keep food fresh for a longer time.

In this calculation model, this additional effect is ascribed to 1.600 kt of food packaging in the sectors small packaging, other bottles, other rigid packaging, and other flexible packaging (equal to 30 % of the total food packaging in these categories). The calculation of the additional effect, based on the data listed above, leads to an energy saving of 3,5 MJ per average kg of plastic packaging (food and non-food packaging) in the four packaging sectors named above. An estimation for the split of this total energy demand into fuels is taken from Weidema [1995], a study about the energy demand for the production of pork and lamb meat. GHG emissions are calculated by multiplying the resulting fuels with the emission factors described in chapter 3.3.

Nevertheless, no profound data is available for the additional effect described; therefore the assumption used can only lead to a possible order of magnitude. The total result of this study regarding the energy saving of all plastic products compared to alternative materials is 1.030 Mill GJ/a. If the effect of additional savings of food are not included in this result, it changes to 1.000 Mill GJ/a.

4.1.1.6 Energy and emissions of waste phase

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The tables below show the resulting database per kg of packaging material.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ
small packaging PS+PP	*direct fuels*	*0,02*									*0,78*		
	substituted fuels	*-2,33*		*-3,94*	*-1,97*	*-0,66*							
	direct & subst. fuels incl. precomb.			-5,45	-2,66	-1,34	-0,46	-3,29	-1,02				
	substituted material production												
small packaging PS+PP	**Total**			**-5,45**	**-2,66**	**-1,34**	**-0,46**	**-3,29**	**-1,02**				
beverage bottles PET	*direct fuels*	*0,36*				*0,32*					*1,51*		
	substituted fuels	*-1,15*		*-3,84*	*-1,92*	*-0,64*							
	direct & subst. fuels incl. precomb.			-4,32	-1,22	-0,59	-0,16	-1,18	-0,36				
	substituted material production			-2,69	-14,07	-7,05	-0,10	-1,30	-0,08	-0,01			-0,22
beverage bottles PET	**Total**			**-7,02**	**-15,30**	**-7,64**	**-0,26**	**-2,48**	**-0,45**	**-0,01**			**-0,22**
other bottles HDPE	*direct fuels*	*0,66*									*1,07*	*0,14*	
	substituted fuels	*-1,71*		*-4,62*	*-2,31*	*-0,77*							
	direct & subst. fuels incl. precomb.			-5,26	-2,16	-1,17	-0,21	-1,56	-0,48				
	substituted material production			-0,49	-6,10	-5,10	-0,09	-0,59	0,00	-0,01			0,01
other bottles HDPE	**Total**			**-5,75**	**-8,26**	**-6,28**	**-0,30**	**-2,15**	**-0,48**	**-0,01**			**0,01**
other rigid packaging HDPE+PS	*direct fuels*	*0,66*									*1,41*	*0,14*	
	substituted fuels	*-1,74*		*-4,71*	*-2,36*	*-0,79*							
	direct & subst. fuels incl. precomb.			-5,38	-1,87	-1,20	-0,22	-1,60	-0,50				
	substituted material production			-0,33	-5,67	-6,73	-0,05	-0,41	-0,01	-0,01			0,02
other rigid packaging HDPE+PS	**Total**			**-5,71**	**-7,54**	**-7,93**	**-0,27**	**-2,01**	**-0,51**	**-0,01**			**0,02**
shrink and stretch films LDPE	*direct fuels*	*2,51*									*1,08*	*0,58*	
	substituted fuels	*-0,36*		*-3,63*	*-1,82*	*-0,61*							
	direct & subst. fuels incl. precomb.			-2,14	0,17	-0,22	0,42	2,87	0,89				
	substituted material production			-2,33	-23,06	-20,90	-0,58	-3,34	0,00	-0,08			-0,02
shrink and stretch films LDPE	**Total**			**-4,47**	**-22,89**	**-21,12**	**-0,16**	**-0,47**	**0,89**	**-0,08**			**-0,02**
carrier bags LDPE	*direct fuels*	*0,66*									*0,87*	*0,14*	
	substituted fuels	*-1,71*		*-4,62*	*-2,31*	*-0,77*							
	direct & subst. fuels incl. precomb.			-5,27	-2,39	-1,17	-0,21	-1,56	-0,48				
	substituted material production			-0,58	-5,76	-5,23	-0,14	-0,84	0,00	-0,02			0,00
carrier bags LDPE	**Total**			**-5,85**	**-8,15**	**-6,40**	**-0,36**	**-2,39**	**-0,48**	**-0,02**			**0,00**
other flexible packaging LDPE	*direct fuels*	*0,35*									*0,83*	*0,07*	
	substituted fuels	*-1,95*		*-4,60*	*-2,30*	*-0,77*							
	direct & subst. fuels incl. precomb.			-5,63	-2,71	-1,30	-0,32	-2,32	-0,72				
	substituted material production			-0,29	-2,88	-2,61	-0,07	-0,42	0,00	-0,01			0,00
other flexible packaging LDPE	**Total**			**-5,92**	**-5,59**	**-3,91**	**-0,39**	**-2,74**	**-0,72**	**-0,01**			**0,00**

Table 32: Database for waste management of plastic packaging: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ
Tin plate low recycling	*direct fuels*	*-0,26*				*-0,02*					*0,33*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			-0,17	0,27	-0,09	-0,05	-0,35	-0,11				
	substituted material production			0,63	0,43	0,35	0,10		0,22	0,01			0,02
Tin plate low recycling	**Total**			**0,45**	**0,70**	**0,27**	**0,05**	**-0,35**	**0,11**	**0,01**			**0,02**
Tin plate high recycling	*direct fuels*	*1,08*				*0,08*					*0,38*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,73	0,82	0,35	0,21	1,49	0,46				
	substituted material production			-2,33	-1,60	-1,31	-0,39		-0,82	-0,05			-0,06
Tin plate high recycling	**Total**			**-1,60**	**-0,79**	**-0,96**	**-0,17**	**1,49**	**-0,35**	**-0,05**			**-0,06**
Aluminium no recycling	*direct fuels*										*0,46*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,51	0,00	0,00	0,01	0,00				
	substituted material production												
Aluminium no recycling	**Total**			**0,00**	**0,51**	**0,00**	**0,00**	**0,01**	**0,00**				
Aluminium high recycling	*direct fuels*	*0,42*			*0,29*	*1,13*					*0,50*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,29	1,08	1,42	0,08	0,59	0,18				
	substituted material production			-6,78	-13,68	-2,55	-11,27	-8,55	0,00	-0,04			0,03
Aluminium high recycling	**Total**			**-6,49**	**-12,60**	**-1,13**	**-11,18**	**-7,96**	**0,19**	**-0,04**			**0,03**
Aluminium medium recycling	*direct fuels*	*0,14*			*0,10*	*0,38*					*0,47*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,10	0,70	0,47	0,03	0,20	0,06				
	substituted material production			-2,26	-4,56	-0,85	-3,76	-2,85	0,00	-0,01			0,01
Aluminium medium recycling	**Total**			**-2,16**	**-3,86**	**-0,38**	**-3,73**	**-2,65**	**0,06**	**-0,01**			**0,01**
Glass low recycling	*direct fuels*										*0,08*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,09	0,00	0,00	0,00	0,00				
	substituted material production			1,68	-1,05	2,96	-0,25	-0,24	-0,04	0,00			
Glass low recycling	**Total**			**1,68**	**-0,96**	**2,96**	**-0,25**	**-0,24**	**-0,04**	**0,00**			
Glass high recycling	*direct fuels*										*0,10*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,11	0,00	0,00	0,00	0,00				
	substituted material production			0,07	-0,05	0,13	-0,01	-0,01	0,00	0,00			
Glass high recycling	**Total**			**0,07**	**0,06**	**0,13**	**-0,01**	**-0,01**	**0,00**	**0,00**			
Glass medium recycling	*direct fuels*										*0,09*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,10	0,00	0,00	0,00	0,00				
	substituted material production			0,66	-0,41	1,16	-0,10	-0,09	-0,02	0,00			
Glass medium recycling	**Total**			**0,66**	**-0,31**	**1,16**	**-0,10**	**-0,09**	**-0,02**	**0,00**			

Table 33: Database for waste management of other packaging materials (I): Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
Corrug. Board / Cardboard low rec.	*direct fuels*	*-0,56*	*-1,03*		*-0,66*	*-4,22*				*-0,19*	*0,51*	*-0,09*	
	substituted fuels	*-0,76*		*-1,35*	*-0,68*	*-0,23*							
	direct & subst. fuels incl. precomb.			-2,40	-2,00	-6,08	-0,28	-1,92	-0,58	0,00	0,00	0,00	-0,10
	substituted material production			0,48	3,58	0,54	1,11	2,48	0,21	12,94	0,00	0,00	0,00
Corrug. Board / Cardboard low rec.	**Total**			**-1,92**	**1,58**	**-5,54**	**0,83**	**0,56**	**-0,37**	**12,94**	**0,00**	**0,00**	**-0,10**
Corrug. Board / Cardboard med. rec.	*direct fuels*	*-0,25*	*-0,52*		*-0,33*	*-2,14*				*-0,10*	*0,61*	*-0,04*	
	substituted fuels	*-0,45*		*-1,33*	*-0,66*	*-0,22*							
	direct & subst. fuels incl. precomb.			-1,87	-1,07	-3,22	-0,15	-1,03	-0,31	0,00	0,00	0,00	-0,05
	substituted material production			0,24	1,81	0,27	0,56	1,25	0,11	6,55	0,00	0,00	0,00
Corrug. Board / Cardboard med. rec.	**Total**			**-1,63**	**0,74**	**-2,94**	**0,41**	**0,23**	**-0,21**	**6,55**	**0,00**	**0,00**	**-0,05**
Corrug. Board / Cardboard high rec.	*direct fuels*	*0,00*	*-0,09*		*-0,05*	*-0,35*				*-0,02*	*1,10*	*-0,01*	
	substituted fuels	*-0,21*		*-1,00*	*-0,50*	*-0,17*							
	direct & subst. fuels incl. precomb.			-1,14	0,37	-0,71	-0,04	-0,31	-0,09	0,00	0,00	0,00	-0,01
	substituted material production			0,04	0,30	0,05	0,09	0,21	0,02	1,08	0,00	0,00	0,00
Corrug. Board / Cardboard high rec.	**Total**			**-1,10**	**0,67**	**-0,66**	**0,05**	**-0,10**	**-0,08**	**1,08**	**0,00**	**0,00**	**-0,01**
Paper / fibre cast low recycling	*direct fuels*	*-0,15*	*-0,29*		*-0,18*	*-1,18*				*-0,05*	*0,54*	*-0,02*	
	substituted fuels	*-0,76*		*-1,35*	*-0,68*	*-0,23*							
	direct & subst. fuels incl. precomb.			-1,99	-0,98	-2,02	-0,19	-1,30	-0,40	0,00	0,00	0,00	-0,03
	substituted material production			0,13	1,00	0,15	0,31	0,69	0,06	3,61	0,00	0,00	0,00
Paper / fibre cast low recycling	**Total**			**-1,86**	**0,02**	**-1,87**	**0,13**	**-0,61**	**-0,34**	**3,61**	**0,00**	**0,00**	**-0,03**
Paper / fibre cast medium recycling	*direct fuels*	*0,16*	*0,22*		*0,14*	*0,90*				*0,04*	*0,63*	*0,02*	
	substituted fuels	*-0,45*		*-1,33*	*-0,66*	*-0,22*							
	direct & subst. fuels incl. precomb.			-1,46	-0,06	0,85	-0,05	-0,41	-0,13	0,00	0,00	0,00	0,02
	substituted material production			-0,10	-0,77	-0,12	-0,24	-0,53	-0,05	-2,77	0,00	0,00	0,00
Paper / fibre cast medium recycling	**Total**			**-1,56**	**-0,82**	**0,73**	**-0,29**	**-0,94**	**-0,17**	**-2,77**	**0,00**	**0,00**	**0,02**
Paper / fibre cast high recycling	*direct fuels*	*0,42*	*0,66*		*0,42*	*2,69*				*0,12*	*1,13*	*0,06*	
	substituted fuels	*-0,21*		*-1,00*	*-0,50*	*-0,17*							
	direct & subst. fuels incl. precomb.			-0,73	1,39	3,36	0,05	0,31	0,09	0,00	0,00	0,00	0,06
	substituted material production			-0,30	-2,28	-0,35	-0,71	-1,58	-0,14	-8,25	0,00	0,00	0,00
Paper / fibre cast high recycling	**Total**			**-1,04**	**-0,90**	**3,01**	**-0,66**	**-1,27**	**-0,05**	**-8,25**	**0,00**	**0,00**	**0,06**
Paperbased composites	*direct fuels*	*0,01*	*0,00*		*0,00*	*0,00*				*0,00*	*0,64*	*0,00*	
	substituted fuels	*-1,10*		*-1,85*	*-0,93*	*-0,31*							
	direct & subst. fuels incl. precomb.			-2,56	-0,95	-0,63	-0,22	-1,54	-0,48	0,00	0,00	0,00	0,00
	substituted material production												
Paperbased composites	**Total**			**-2,56**	**-0,95**	**-0,63**	**-0,22**	**-1,54**	**-0,48**	**0,00**	**0,00**	**0,00**	**0,00**
Wood, textile, etc.	*direct fuels*	*0,01*	*0,00*		*0,00*	*0,00*				*0,00*	*1,09*	*0,00*	
	substituted fuels	*-0,75*		*-1,26*	*-0,63*	*-0,21*							
	direct & subst. fuels incl. precomb.			-1,74	0,08	-0,43	-0,15	-1,04	-0,32	0,00	0,00	0,00	0,00
	substituted material production												
Wood, textile, etc.	**Total**			**-1,74**	**0,08**	**-0,43**	**-0,15**	**-1,04**	**-0,32**	**0,00**	**0,00**	**0,00**	**0,00**

Table 34: Database for waste management of other packaging materials (II): Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
small packaging PS+PP	emissions from electr./steam/fuels	-846.746	-1.447	3
	CO2 from incinerated waste	1.305.495		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
small packaging PS+PP	**Total**	**458.749**	**-1.447**	**3**
beverage bottles PET	emissions from electr./steam/fuels	-541.705	-908	10
	CO2 from incinerated waste	702.778		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-1.014.394	-3.322	0
beverage bottles PET	**Total**	**-853.321**	**-4.231**	**10**
other bottles HDPE	emissions from electr./steam/fuels	-735.118	-1.234	5
	CO2 from incinerated waste	1.162.857		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-262.190	-1.460	0
other bottles HDPE	**Total**	**165.550**	**-2.694**	**5**
other rigid packaging HDPE+PS	emissions from electr./steam/fuels	-726.802	-1.231	8
	CO2 from incinerated waste	1.207.582		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-338.527	-1.459	0
other rigid packaging HDPE+PS	**Total**	**142.254**	**-2.690**	**8**
shrink and stretch films LDPE	emissions from electr./steam/fuels	-107.016	-133	6
	CO2 from incinerated waste	582.256		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-1.104.558	-5.961	0
shrink and stretch films LDPE	**Total**	**-629.319**	**-6.094**	**6**
carrier bags LDPE	emissions from electr./steam/fuels	-751.637	-1.255	3
	CO2 from incinerated waste	1.162.857		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-276.140	-1.490	0
carrier bags LDPE	**Total**	**135.081**	**-2.745**	**3**
other flexible packaging LDPE	emissions from electr./steam/fuels	-836.269	-1.406	2
	CO2 from incinerated waste	1.243.673		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-138.070	-745	0
other flexible packaging LDPE	**Total**	**269.335**	**-2.152**	**2**

Table 35: Database for waste management of plastic packaging: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
Tin plate low recycling	emissions from electr./steam/fuels	-11.137	-37	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	104.880	229	3
Tin plate low recycling	**Total**	**93.743**	**191**	**6**
Tin plate high recycling	emissions from electr./steam/fuels	186.212	330	4
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-390.678	-853	-11
Tin plate high recycling	**Total**	**-204.466**	**-523**	**-8**
Aluminium no recycling	emissions from electr./steam/fuels	37.044	46	4
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions			
Aluminium no recycling	**Total**	**37.044**	**46**	**4**
Aluminium high recycling	emissions from electr./steam/fuels	192.742	363	5
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-1.746.101	-4.031	-5
Aluminium high recycling	**Total**	**-1.553.358**	**-3.669**	**0**
Aluminium medium recycling	emissions from electr./steam/fuels	88.943	152	5
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-582.034	-1.344	-2
Aluminium medium recycling	**Total**	**-493.090**	**-1.192**	**3**
Glass low recycling	emissions from electr./steam/fuels	6.608	8	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	259.921	-448	-1
Glass low recycling	**Total**	**266.529**	**-440**	**0**
Glass high recycling	emissions from electr./steam/fuels	7.820	10	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	11.301	-19	0
Glass high recycling	**Total**	**19.121**	**-10**	**1**
Glass medium recycling	emissions from electr./steam/fuels	7.375	9	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	101.708	-175	0
Glass medium recycling	**Total**	**109.083**	**-166**	**1**

Table 36: Database for waste management of other packaging materials (I): Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
Corrug. Board / Cardboard low rec.	emissions from electr./steam/fuels	-734.667	-1.470	2
	CO2 from incinerated waste	0		
	CH4 from landfill (wood, paper)		74.834	
	subst. production emissions	332.387	498	6
Corrug. Board / Cardboard low rec.	**Total**	**-402.280**	**73.862**	**9**
Corrug. Board / Cardboard med. rec.	emissions from electr./steam/fuels	-443.679	-868	4
	CO2 from incinerated waste	0		
	CH4 from landfill (wood, paper)		44.020	
	subst. production emissions	168.303	252	3
Corrug. Board / Cardboard med. rec.	**Total**	**-275.376**	**43.404**	**7**
Corrug. Board / Cardboard high rec.	emissions from electr./steam/fuels	-121.458	-250	9
	CO2 from incinerated waste	0		
	CH4 from landfill (wood, paper)		20.852	
	subst. production emissions	27.660	41	1
Corrug. Board / Cardboard high rec.	**Total**	**-93.798**	**20.643**	**10**
Paper / fibre cast low recycling	emissions from electr./steam/fuels	-393.590	-739	3
	CO2 from incinerated waste	0		
	CH4 from landfill (wood, paper)		74.834	
	subst. production emissions	92.825	139	2
Paper / fibre cast low recycling	**Total**	**-300.766**	**74.234**	**5**
Paper / fibre cast medium recycling	emissions from electr./steam/fuels	-102.602	-137	5
	CO2 from incinerated waste	0		
	CH4 from landfill (wood, paper)		44.020	
	subst. production emissions	-71.259	-107	-1
Paper / fibre cast medium recycling	**Total**	**-173.862**	**43.776**	**3**
Paper / fibre cast high recycling	emissions from electr./steam/fuels	219.619	481	10
	CO2 from incinerated waste	0		
	CH4 from landfill (wood, paper)		20.852	
	subst. production emissions	-211.903	-318	-4
Paper / fibre cast high recycling	**Total**	**7.716**	**21.015**	**6**
Paperbased composites	emissions from electr./steam/fuels	-375.987	-653	4
	CO2 from incinerated waste	251.429		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
Paperbased composites	**Total**	**-124.558**	**-653**	**4**
Wood, textile, etc.	emissions from electr./steam/fuels	-204.130	-380	9
	CO2 from incinerated waste	0		
	CH4 from landfill (wood, paper)		111.359	
	subst. production emissions			
Wood, textile, etc.	**Total**	**-204.130**	**110.979**	**9**

Table 37: Database for waste management of other packaging materials (II): Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

4.1.2 Beverage packaging

4.1.2.1 Mass ratios

Energy consumption and emissions caused by beverage packaging systems are strongly influenced by two factors, i.e. the material of the beverage packaging itself and the distribution system, which can be a one-way system or a refillable system. Recent studies have confirmed that the differences between systems can be as high or even higher than the differences between materials.

In this study only the difference between plastics and alternative materials should be investigated. A mixture of effects of different materials and of different systems would confuse the results and conclusions of this study which are only orientated on the comparison of materials. Therefore it is important within the scope of this study that one-way bottles are only compared with one-way bottles and refillable bottles are only compared with refillable bottles.

But the combination of the principle described and of the current market of beverage packaging does not directly lead to a realistic scenario, because such a scenario would basically describe a substitution of PET one-way bottles by glass one-way bottles, cans and beverage cartons. Yet, looking at beverage packaging market pf the past, a substitution scenario with no glass refillable bottles at all is not a very credible assumption.

Therefore, to fulfil the methodical needs of this study, a theoretical, but much more realistic scenario is chosen for the following comparison. The thinking behind the scenario is “backwards”, meaning to introduce plastic bottles to a beverage market without plastic bottles (without changing the systems) instead of substituting the plastic bottles on the current beverage market.

This means, starting from a beverage system without plastic bottles, PET refillable bottles are introduced to substitute glass refillable bottles, and PET one-way bottles are used to replace glass one-way bottles, cans and beverage cartons. Existing systems based on PET refillable prove that they would be possible if the consumer would prefer such a system. In the sector of carbonated drinks PET can substitute glass or cans. In the sectors water without gas, milk, and a small part of juices including ice tea, PET can additionally replace beverage carton.

For the composition of a market without PET bottles, different scenarios can be assumed: Scenarios with a high share of refillable glass bottles and scenarios with a low share of refillable glass bottles (see table below).

Szenario high refillable share			
	1,0 l	**0,5 l**	**0,33 l**
Glass REF	68%	5%	4%
Glass OW	7%	0%	3%
Aluminium can		3%	
Tin plate can		3%	
Beverage carton	7%		

Szenario low refillable share			
	1,0 l	**0,5 l**	**0,33 l**
Glass REF	7%	0%	3%
Glass OW	68%	5%	4%
Aluminium can		3%	
Tin plate can		3%	
Beverage carton	7%		

Selected szenario			
	1,0 l	**0,5 l**	**0,33 l**
Glass REF	25%	2%	3%
Glass OW	50%	4%	4%
Aluminium can		3%	
Tin plate can		3%	
Beverage carton	7%		

Table 38: *Scenarios with different shares of refillable beverage packaging. In this study, the average scenario has been used as a basis for calculation.*

The scenario with the high share of refillable glass bottles was derived from detailed data on the German beverage packaging market in 1998, provided by GVM, split into water and soft drinks (including juices), beer and milk, which are the beverage sectors with relevant shares of PET packaging. The data were aggregated by using the litres consumed in PET in Western Europe in 2002 for the three beverage sectors named above. The reuse quota in this scenario is 77 %.

The scenario with the lower share of refillable glass bottles was estimated in a way that

- the reuse quota is 10 % (in 2003, about 9 % of the total filling volume in PET bottles was filled in PET refillable bottles in Western Europe, estimated by PETCORE – www.petcore.org)
- the total market shares of a certain bottle volume remained constant.

In this study, a **scenario with a refillable quota of 30 %** is chosen, calculated as a mix of 70 % of the "scenario low refillable share" and 30 % of the "scenario high refillable share".

The table below shows the resulting substitution model for beverage packaging. For glass refillable bottles, 40 reuse cycles are assumed, for PET refillable bottles, 10 reuse cycles are assumed. Data on the specific mass of the packaging materials was derived from an overview of values extracted from different studies (see Table 41)

	1,5 l	**1,0 l**	**0,5 l**	**0,33 l**	**Total**	**1,5 l**	**1,0 l**	**0,5 l**	**0,33 l**	**1,5 l**	**1,0 l**	**0,5 l**	**0,33 l**
	Volume in PET & alternat. materials					**Pack. mass [g/l]**				**Number of cycles**			
Glass REF		25%	2%	3%	30%		629	720	1000		40	40	40
↓													
PET REF	25%		5%		30%	63		96		10		10	
Glass OW		50%	4%	4%	57%		382	528	667		1	1	1
Aluminium can			3%		3%			30				1	
Tin plate can			3%		3%			71				1	
Beverage carton		7%			7%		25				1		
↓													
PET OW	57%		13%		70%	26		49		1		1	
Total in PET	82%		18%		100%								
Total in alt. material		82%	11%	7%	100%								

Table 39: Substitution model for beverage packaging, part 1

	1,5 l	1,0 l	0,5 l	0,33 l	average g/l within materials	produced PET for 1 av. litre	produced alternative materials for 1 av. litre	mass ratios used
	Produced pack. mass [g/l]							
Glass REF		16	18	25	**16,8**		**5,1**	**0,22**
↓								
PET REF	6		10		**6,8**	**2,1**		
Glass OW		382	528	667	**409,7**		**233,1**	**10,06**
Aluminium can			30		**30,5**		**0,9**	**0,04**
Tin plate can			71		**71,1**		**2,1**	**0,09**
Beverage carton		25			**25,3**		**1,8**	**0,08**
↓								
PET OW	26		49		**30,2**	**21,1**		
Total in PET						**23,2**		**1,00**
Total in alt. material							**243,0**	**10,49**

Table 40: Substitution model for beverage packaging, continued

Packaging unit	**Beverage sector**	**Mass [g]**	**g/l**	**Source**
1l REF light glass bottle	carbonated mineral water	490,0	**490,0**	Prognos 2002 S.28
1l OW light glass bottle	carbonated mineral water	298,0	**298,0**	Prognos 2002 S.28
1 l glass REF	soft drinks	628,5	**628,5**	GUA 2000b
1l PET OW	carbonated mineral water	32,0	**32,0**	Prognos 2002 S.29
1,5l PET OW	carbonated mineral water, soft drinks	35,0	**23,3**	Prognos 2002 S.29
		42,0	**28,0**	DEPA 405 1998 S. 25
		39,0	**26,0**	GUA 2000b
		39,0	**26,0**	RDC/PIRA 2003 Annex 12
1,5l PET OW	water without gas	28,0	**18,7**	Prognos 2002 S.30
1,5l PET REF	soft drinks	105,0	**70,0**	DEPA 404 1998 S. 27
	carbonated mineral water	84,0	**56,0**	GUA 2000b
	soft drinks	106,3	**70,9**	GUA 2000b
	soft drinks	84,0	**56,0**	RDC/PIRA 2003 Annex 12
0,5l PET REF	carbonated mineral water	43,0	**86,0**	Prognos 2002 S.31
		53,0	**106,0**	DEPA 404 1998 S. 16
0,5l PET OW	carbonated mineral water	21,0	**42,0**	Prognos 2002 S.31
		28,0	**56,0**	DEPA 405 1998 S. 14
0,5l glass REF	soft drinks	360,0	**720,0**	Prognos 2002 S.32
	beer	382,0	**764,0**	GUA 2000b
0,5l Al can	soft drinks	12,0	**23,9**	Prognos 2002 S.32
0,5l Al can	soft drinks	18,5	**37,0**	DEPA 402 1998 S. 26
	beer	18,3	**36,6**	GUA 2000b
0,33 l Al can	soft drinks	14,5	**43,8**	DEPA 402 1998 S. 15
0,33 l tin plate can	soft drinks	28,2	**85,3**	DEPA 403 1998 S. 16
0,5l tin plate can	soft drinks	30,9	**61,8**	Prognos 2002 S.32
	soft drinks	40,2	**80,4**	DEPA 403 1998 S. 28
	beer	37,5	**75,1**	GUA 2000b
0,33 l glass REF	beer	300,0	**909,1**	DEPA 400 1998 S. 16
	soft drinks	330,0	**1000,0**	RDC/PIRA 2003 Annex 12
0,33 l glass OW	soft drinks	220,0	**666,7**	RDC/PIRA 2003 Annex 12
0,25 l glass REF	soft drinks	240,0	**960,0**	DEPA 400 1998 S. 28
1l beverage carton	milk	25,3	**25,3**	GUA 2000b

Table 41: Data on specific mass of different beverage packaging in different studies.

The substitution model leads to an average PET mass of 23,2 g per litre. The mass ratios are calculated by dividing the masses of alternative materials per litre by 23,2 g PET per litre.

The higher proportion of PET refillable bottles in the theoretical scenario leads to a lower PET mass for beverage packaging (needed for the same filling volume) than on the current market. In 2003 about 9 % of the total filling volume in PET bottles was filled in PET refillable bottles in Western Europe. The corresponding average PET mass is 27,9 g. The PET mass in the theoretical scenario is therefore only 83 % of the PET mass on the current market (23,2 / 27,9 = 0,83). For the calculations it has been preferred not to change the market figure for PET beverage bottles in Western Europe. Instead the calculations for 1 kg PET on the market as well as for the mass of substituting materials are multiplied with the factor 0,83 (see also chapter 3.2).

Changes regarding crates and shrink film masses due to a substitution of PET beverage packaging by other materials are not included in the calculation. Nevertheless, the result is conservative from the perspective of plastics, because e.g. crates for glass refillable bottles (approx. 170 g/l [GUA 2000b]) are heavier than crates for PET refillable bottles (approx. 130 g/l), etc.

4.1.2.2 Energy and emissions of production phase

See chapter 4.1.1.4

4.1.2.3 Energy and emissions of use phase

For beverage packaging, the different energy demand for transportation of beverage packaging from packaging producers to fillers and between fillers and shops are considered as an effect in the use phase. The differences in diesel needed for transportation are a result of the different packaging masses per litre, but even more of the different demands of space needed in the truck (litres per truck).

A detailed calculation of the effect described cannot be carried out within the scope of this study. For an estimation of the effect, the differences between PET refillable and glass refillable bottles as well as the differences between PET one-way and glass one-way bottles are considered. The differences in transportation energy are assumed be much lower for the comparison of PET one-way with cans and beverage cartons.

Data about fuel needed for transportation of empty and full beverage packaging are taken from a detailed study of GUA [2000b] on beverage systems. For the transportation processes described above, the study calculates 14,9 kg Diesel per 1.000 litres for glass refillable bottles and 8,0 kg Diesel per 1.000 litres for PET refillable bottles. The diesel saved in the case of PET refillable is 6,8 kg per 1.000 litres or 1,08 kg diesel per kg PET (assuming 10 reuse cycles for PET refillable). The saving by PET in case of the one-way system is 6,4 kg diesel per 1.000 litres but only 0,25 kg diesel per kg PET (no reuse cycles). Taking the market shares of PET one-way and PET refillable bottles of the theoretical model used in this study into account, the average saving comes to 0,26 kg diesel per kg PET or 11,7 MJ diesel per kg PET.

The total transport energy for an average kg PET in form of beverage packaging (calculated in the same way) is 13,7 MJ diesel. Therefore the total energy for the average glass beverage packaging is 25,4 kg per kg substituted PET. The amount of glass needed (among other materials) to substitute 1 kg of PET is 7,82 kg. Therefore the total transport energy needed per 1 average kg glass is 25,4 / 7,82 = 3,25 MJ diesel (3,7 MJ after precombustion is included).

4.1.2.4 Energy and emissions of waste phase

See chapter 4.1.1.6.

4.2 Building: Pipes

According to market data available for plastic pipes and data on mass ratios for plastic pipes and pipes made of other materials, nine different case studies for pipes are assessed in this study:

- drain and sewer pipes, big diameter
- drain and sewer pipes, small diameter
- drinking water pipes, big diameter
- drinking water pipes, small diameter
- agricultural pipes
- conduit pipes
- gas pipes
- heating & plumbing pipes
- industry pipes

4.2.1.1 Market share of plastic products and split into polymers

Market data on plastic pipes in the seven application sectors listed above was taken from IAL [2003]. Polymer composition for total plastic pipe mass and within the application sectors was estimated, based on data from PlasticsEurope [1997] regarding total polymer masses for pipes and on estimated judgement of TEPPFA and experts in the pipe market. The original figure of IAL for the share of PVC in the total plastic pipe market was 56 %, but the resulting share of PVC pipes in the sector of drain and sewer pipes was to low in the opinion of TEPPFA.

In the following calculations, the sectors “drain and sewer pipes” and “drinking water pipes” are split into two categories, namely big diameter and small diameter. The reason is that studies show quite different mass rations for different diameters of these pipes.

Nevertheless, “big” and “small” are not very well defined in this study. “Big” for drain and sewer pipes means a diameter of more than approx. 200 mm; “big” for drinking water pipes means a diameter of more than approx. 100 mm.

Market data distinguishing between these two categories was not available for this study. Therefore a share of 50 % for each category, big and small pipes, is assumed for drain and sewer pipes as well as for drinking water pipes.

Plastic pipes by sector and polymer	**drain and sewer pipes**	**drinking water pipes**	**agricultural pipes**	**conduit pipes**	**gas pipes**	**heating & plumbing pipes**	**industry pipes**	**Total Market (2002)**
Pipe market by sectors	***49%***	***21%***	***9%***	***8%***	***5%***	***4%***	***4%***	***100%***
PVC	75,0%	56,0%	75,0%	95,0%			29,0%	64,0%
HDPE	15,0%	40,0%	15,0%	5,0%	100,0%		50,0%	24,5%
PP	10,0%		10,0%			45,0%	6,0%	6,3%
PE-X		4,0%				55,0%	3,3%	4,6%
ABS							11,7%	0,7%
Total	100%	100%	100%	100%	100%	100%	100%	100%

Plastic pipes by sector and polymer, in 1.000 t	**drain and sewer pipes**	**drinking water pipes**	**agricultural pipes**	**conduit pipes**	**gas pipes**	**heating & plumbing pipes**	**industry pipes**	**Total Market (2002)**
PVC	1.055	338	194	218			33	1.839
HDPE	211	241	39	11	144		57	704
PP	141		26			52	7	180
PE-X		24				63	4	131
ABS							13	19
Total	1.407	603	258	230	144	115	115	**2.872**

Table 42: Market data for plastic pipes by sector and polymer

4.2.1.2 Mass ratios

To derive the mass ratios used in the calculation model of this study, several steps have to be taken. The first step tries to describe the market of pipes made of alternative materials. Alternative materials that can possibly substitute plastic pipes in the application sector investigated were defined by analysing several studies about the comparison of pipes made from different materials. The market share of alternative materials was assumed following estimated judgement of TEPPFA and experts in the pipe market.

	drain and sewer pipes, big diameter	**drain and sewer pipes, small diameter**	**drinking water pipes, big diameter**	**drinking water pipes, small diameter**	**agricultural pipes**	**conduit pipes**	**gas pipes**	**heating & plumbing pipes**	**industry pipes**
stainless steel		5%		15%	5%		50%	30%	25%
zinc coated iron				35%			50%		
cast iron	10%	30%	60%		30%			30%	25%
copper			10%	50%				40%	25%
stoneware	30%	30%			30%				
concrete	55%								
fibrecement	5%	30%	30%		30%				
leaded steel/paper						100%			
aluminium		5%			5%				25%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 43: Assumptions for the substitution of plastic pipes by alternative materials on the level of functional units (e.g. 1 meter of pipe)

Mass ratios on the level of single products (mass of non plastic pipe divided by mass of plastic pipe) were extracted from seven studies dealing with the comparison of pipes made of different materials (see next table).

Study / material	Appl. sector	Diam.[mm]	Mass/FU	MR - PVC	MR - HDPE	MR - PE-X
EMPA						
HDPE	drinking wate	32/200	3722			
PVC	drinking wate	32/200	3114			
cast iron	drinking wate	32/200	8447	**2,71**	**2,27**	
HDPE	waste water	150/200	2184			
PVC	waste water	150/200	2135			
stoneware	waste water	150/200	5568	**2,61**	**2,55**	
TU-Wien						
PVC	drinking wate	150	5,32			
HDPE	drinking wate	150	6,6			
fibre cement	drinking wate	150	16	**3,01**	**2,42**	
cast iron	drinking wate	150	26	**4,89**	**3,94**	
PVC	waste water	250	6,59			
HDPE	waste water	250	7,2			
stoneware	waste water	250	51	**7,74**	**7,08**	
concrete	waste water	250	125	**18,97**	**17,36**	
fibre cement	waste water	250	24	**3,64**	**3,33**	
cast iron	waste water	250	38	**5,77**	**5,28**	
PVC	rain water	400	16,8			
HDPE	rain water	400	12,1			
stoneware	rain water	400	142	**8,45**	**11,74**	
concrete	rain water	400	218	**12,97**	**18,02**	
fibre cement	rain water	400	60	**3,57**	**4,96**	
cast iron	rain water	400	60	**3,57**	**4,96**	
Geberit						
PE-X	drinking wate	20	0,23			
steel, stainless	drinking wate	20	0,62			**2,70**
zinc coated iron	drinking wate	20	1,58			**6,87**
copper	drinking wate	20	0,59			**2,57**
PVC	waste water	100	1,04			
HDPE	waste water	100	1,36			
cast iron	waste water	100	8,8	**8,46**	**6,47**	
fibre cement	waste water	100	5,6	**5,38**	**4,12**	
Franklin						
Copper	pressure pip	203		**6,40**	**9,60**	
Cast Iron	pressure pip	203		**7,40**	**11,10**	
Steel	pressure pip	203		**5,70**	**8,50**	
Cast Iron	drain, waste,	76		**4,50**		
Copper	drain, waste,	76		**1,30**		
Steel	drain, waste,	76		**5,70**		
Steel	conduit			**6,00**		
Concrete/Aggregate	conduit			**6,00**		
Copper	conduit			**3,60**		
Cast Iron	Sewer & drai	610		**5,30**	**14,00**	
Stoneware	Sewer & drai	610		**3,60**	**9,90**	
Concrete/Aggregate	Sewer & drai	610		**2,60**	**7,00**	
Copper	other	203		**6,40**	**9,60**	
Cast Iron	other	203		**7,40**	**11,10**	
Steel	other	203		**2,50**	**5,80**	
Aluminum	other	203		**3,20**	**4,80**	
Concrete/Aggregate	other	203		**5,40**	**6,00**	
Entec						
PVC	rainwater pip	68	0,62			
aluminium	rainwater pip	63	0,86	**1,39**		
GUA						
PVC	conduit pipe	20	0,07			
steel	conduit pipe	20	0,32	**4,57**		
Gastec						
HDPE	gas, high pr.	110/160	77,7			
PE-X	gas, high pr.	110/160	77,1			
steel	gas, high pr.	100/150	207		**2,67**	**2,69**
PVC	gas, low pr.	**63**/160	108			
HDPE	gas, low pr.	**63**/160	144			
nodular iron	gas, low pr.	**80**/150	1528	**14,10**	**10,59**	

Table 44: Values for mass ratios in various studies dealing with the comparison of pipes made of different materials. FU = Functional Unit, e.g. 1 meter of pipe. MR = mass ratio.

The mass ratios used in different studies vary considerably. Where several mass ratios were available for one application sector, the calculations in the model of this study were based on mean values. For some case studies only one single value was available.

With the data currently available it remains unclear, if the selected values represent a reasonable mean value of a wide spectrum of possible mass ratios on the market or not. Further investigations in this field are recommended. The following table shows the mass ratios selected:

	drain and sewer pipes, big diameter	**drain and sewer pipes, small diameter**	**drinking water pipes, big diameter**	**drinking water pipes, small diameter**	**agricultural pipes**	**conduit pipes**	**gas pipes**	**heating & plumbing pipes**	**industry pipes**
Mass ratios for comparison with PVC pipes									
stainless steel		5,70		3,22	5,70				4,61
zinc coated iron				8,21					
cast iron	4,67	8,46	3,80		8,46				8,46
copper			6,40	3,07					3,35
stoneware	8,45	5,17							
concrete	15,97								
fibrecement	3,61	5,38	3,01		5,38				
leaded steel/paper						4,57			
aluminium		1,39			1,39				1,39
Mass ratios for comparison with HDPE pipes (and other polymers)									
stainless steel		4,36		2,70	4,36		2,68	2,70	3,53
zinc coated iron				6,87			10,59		
cast iron	5,12	6,47	3,10		6,47			3,10	6,47
copper			9,60	2,57				2,57	2,57
stoneware	11,74	4,82							
concrete	17,69								
fibrecement	4,15	4,12	2,42		4,12				
leaded steel/paper									
aluminium		1,06			1,06				1,06

Table 45: Mass ratios selected for calculating the substitution of plastic pipes by pipes made of alternative materials.

In the next step, the mass ratios relevant for PVC pipes and the mass ratios relevant for HDPE pipes and pipes made of other polymers are aggregated by using the share of PVC in every application sector (see Table 42). Additionally, assumptions regarding different lifetimes are included in the calculation of mass ratios. Different lifetimes are in this study only assumed for big and small drain & sewer pipes: The lifetime of pipes made of stainless steel and of cast iron is assumed to be 50 % longer than the lifetime of the respective plastic pipes. For stoneware, a 25 % longer lifetime is assumed. The resulting mass ratios (still on the level of single products) are:

	drain and sewer pipes, big diameter	**drain and sewer pipes, small diameter**	**drinking water pipes, big diameter**	**drinking water pipes, small diameter**	**agricultural pipes**	**conduit pipes**	**gas pipes**	**heating & plumbing pipes**	**industry pipes**
stainless steel		3,58		2,99	3,58		2,68	2,70	3,84
zinc coated iron				7,62			10,59		
cast iron	3,19	5,31	3,49		5,31			3,10	7,05
copper			7,81	2,85				2,57	2,79
stoneware	7,42	4,07			4,07				
concrete	16,40								
fibrecement	3,74	5,07	2,75		5,07				
leaded steel/paper						4,34			
aluminium		1,31			1,31				1,16

Table 46: Mass ratios for the mix of polymers used for plastic pipes and including assumptions of different lifetime.

These values, combined with the total masses of plastic pipes used in each application sector and with the market shares of alternative materials in case of substitution, lead to the mass of alternative materials substituting all plastic pipes in every application sector.

	drain and sewer pipes, big diameter	**drain and sewer pipes, small diameter**	**drinking water pipes, big diameter**	**drinking water pipes, small diameter**	**agricultural pipes**	**conduit pipes**	**gas pipes**	**heating & plumbing pipes**	**industry pipes**	**Total**
stainless steel		126		135	46		192	93	110	**703**
zinc coated iron				804			760			**1.565**
cast iron	224	1.121	632		412			107	202	**2.698**
copper			235	429				118	80	**863**
stoneware	1.565	859			315					**2.739**
concrete	6.346									**6.346**
fibrecement	132	1.070	249		393					**1.843**
leaded steel/paper						998				**998**
aluminium		46			17				33	**96**
Total	**8.267**	**3.221**	**1.116**	**1.369**	**1.183**	**998**	**953**	**318**	**426**	**17.851**

Table 47: Mass of alternative materials substituting all plastic pipes in every application sector.

The final mass ratios used in this calculation model, are now directly derived from Table 42 and Table 47.

Table of mass ratios	**Market share plastics**	**Plastics total**	HDPE	PP	PVC	**PE-X,** PMMA	**ABS**/SAN & oth. thermopl.	**Altern. mat. - Total**	Steel	Zinc coated iron	Cast iron	Aluminium	Copper	Fibrecement	Stoneware	Concrete
big drain & sewer pipes	1,69%	**1,00**	0,15	0,10	0,75			11,75			0,32			0,19	2,22	9,02
small drain & sewer pipes	1,69%	**1,00**	0,15	0,10	0,75			4,58	0,18		1,59	0,07		1,52	1,22	
big drinking water pipes	0,73%	**1,00**	0,40		0,56	0,04		3,70			2,10		0,78	0,83		
small drinking water pipes	0,73%	**1,00**	0,40		0,56	0,04		4,54	0,45	2,67			1,42			
agricultural pipes	0,62%	**1,00**	0,15	0,10	0,75			4,58	0,18		1,59	0,07		1,52	1,22	
conduit pipes	0,55%	**1,00**	0,05		0,95			4,34	4,34							
gas pipes	0,35%	**1,00**	1,00					6,63	1,34	5,29						
heating & plumbing pipes	0,28%	**1,00**		0,45		0,55		2,77	0,81		0,93		1,03			
industry pipes	0,28%	**1,00**	0,50	0,06	0,29	0,03	0,12	3,71	0,96		1,76	0,29	0,70			

Table 48: Mass ratios for the substitution of plastic pipes used in this study

4.2.1.3 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- PVC and HDPE pipes for waste water and drinking water: EMPA [1998].
- For pipes made of PP and ABS, the energy needed to produce PP granulate and ABS granulate (PlasticsEurope inventories) was combined with the processing energy of HDPE pipes.
- Cast iron pipes: EMPA [1998].
- Zinc coated iron pipes: Data for cast iron pipes was combined with data for zinc coating [Ecoinvent 2004].
- In this study, data per kg zinc coated iron pipe was also used as a conservative estimate for 1 kg of stainless steel pipe. For a more accurate calculation, data from Ecoinvent [2004] for high alloyed steel 18/8 (18 % Cr, 8 % Ni; “stainless steel”) could be used (68 MJ/kg for stainless steel instead of 22 MJ/kg for cast iron). This inaccuracy favours the results for alternative materials; the simplification is therefore conservative from the perspective of plastics.
- Data for aluminium pipes was not available. As an estimate, data for aluminium packaging film were corrected regarding processing energy: From the values for aluminium film, the energy for “aluminium sheet rolling” ([Ecoinvent 2004], multiplied with 2 because we assumed that the aluminium film for packaging is thinner than the product of “sheet rolling) was subtracted and the energy for “aluminium extrusion” [Ecoinvent 2004] was added.
- Copper pipes: Data for primary copper [Ecoinvent 2004] was combined with processing energy of cast iron pipes, derived from EMPA [1998] and Ecoinvent [2004].
- Stoneware pipes: EMPA [1998].
- Fibrecement pipes and concrete pipes: TU-Wien [1996]. Data of this study is based on net heating values and the Austrian electricity mix. The values were therefore corrected to produce data based on gross heating values and the European electricity mix generally used in this study. Due to the correction the values increased for about 30 – 50 % (concrete: 0,8 MJ/kg instead of 0,54 MJ/kg; fibrecement: 7,6 MJ/kg instead of 5,8 MJ/kg). GHG emissions are calculated by multiplying fuels with the emission factors described in chapter 3.3. It remained unclear, to what extent precombustion energy is included in the data. In any case, the results based on the data used are conservative from the perspective of plastic products.

Material	Product	Total energy demand MJ/kg	coal MJ/kg	oil MJ/kg	gas MJ/kg	hydro MJ/kg	nuclear MJ/kg	lignite MJ/kg	wood / biomass MJ/kg	other MJ/kg
PVC	WW pipe	**77,30**	8,75	24,72	28,57	1,09	11,55	2,46	0,00	0,16
HDPE	WW pipe	**93,56**	4,59	37,46	41,55	0,71	6,05	3,15	0,00	0,04
PVC	DW pipe	**77,13**	8,36	25,27	29,21	1,06	10,93	2,15	0,00	0,15
HDPE	DW pipe	**92,29**	3,91	38,00	42,05	0,65	5,02	2,62	0,00	0,04
PP	pipe	**89,63**	3,76	42,07	34,94	0,43	5,35	3,14	-0,04	-0,03
ABS	pipe	**110,36**	4,22	33,75	64,92	0,20	3,02	4,26	-0,06	0,06
Steel, zinc coated iron	pipe	**34,93**	14,18	4,59	7,47	1,63	4,26	2,54	0,03	0,22
Cast iron	DW pipe	**27,42**	13,17	2,39	5,00	0,32	4,26	2,09	0,00	0,19
Aluminium	pipe	**190,56**	30,52	58,32	16,08	47,71	35,18	2,00	0,76	0,00
Copper	pipe	**34,13**	8,65	5,37	8,91	5,14	4,26	1,38	0,30	0,13
Fibrecement	WW pipe	**7,59**	1,98	2,42	0,72	0,16	1,94	0,37	0,00	0,00
Stoneware	WW pipe	**27,01**	0,99	4,51	18,09	0,35	2,43	0,51	0,00	0,13
Concrete	pipe	**0,79**	0,23	0,24	0,06	0,03	0,18	0,06	0,00	0,00

Material	Product	CO_2 mg/kg	CH_4 mg/kg	N_2O mg/kg
PVC	WW pipe	2.442.643	6.776	11,6
HDPE	WW pipe	2.670.728	5.049	10,1
PVC	DW pipe	2.406.541	6.671	11,2
HDPE	DW pipe	2.584.825	4.829	9,5
PP	pipe	2.741.747	3.680	10,1
ABS	pipe	4.110.526	6.036	9,6
Steel, zinc coated iron	pipe	2.129.540	6.982	27,4
Cast iron	DW pipe	1.653.401	6.421	8,1
Aluminium	pipe	8.076.900	17.806	43,8
Copper	pipe	1.988.901	5.431	210,6
Fibrecement	WW pipe	432.572	711	1,9
Stoneware	WW pipe	1.359.204	3.380	15,7
Concrete	pipe	45.810	75	0,2

Table 49: Energy demand and emissions of the production phase of pipes used in this calculation model. "WW" = waste water; "DW" = drinking water.

4.2.1.4 Energy and emissions of use phase

No effects in the use phase of pipes are considered in this study. Assumed differences regarding lifetime are already included in the calculation of the mass ratios used (see above).

4.2.1.5 Energy and emissions of waste phase

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. For the waste management phase of pipes it is assumed that a part or the total amount of pipes is left in the ground (see Table 50). Table 51 to Table 54 show the resulting database per kg of available pipe waste, which turns up in waste management.

big drain and sewer pipes	100%
small drain and sewer pipes	50%
big drinking water pipes	100%
small drinking water pipes	50%
agricultural pipes	50%
conduit pipes	20%
gas pipes	50%
heating and plumbing pipes	20%
industry pipes	20%

Table 50: Share of pipes staying in the ground.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
small drain and sewer p. HDPE low re	*direct fuels*	*0,33*									*0,35*	*0,07*	
	substituted fuels	*-0,98*		*-2,03*	*-1,01*	*-0,34*							
	direct & subst. fuels incl. precomb.			-2,44	-1,15	-0,56	-0,13	-0,94	-0,29				
	substituted material production			-0,24	-3,05	-2,55	-0,05	-0,29	0,00	-0,01			0,00
small drain and sewer p. HDPE low re	**Total**			**-2,68**	**-4,19**	**-3,11**	**-0,18**	**-1,24**	**-0,29**	**-0,01**			**0,00**
conduit pipes HDPE zero recycling	*direct fuels*	*0,01*									*0,32*		
	substituted fuels	*-1,10*		*-1,72*	*-0,86*	*-0,29*							
	direct & subst. fuels incl. precomb.			-2,44	-1,22	-0,60	-0,22	-1,55	-0,48				
	substituted material production												
conduit pipes HDPE zero recycling	**Total**			**-2,44**	**-1,22**	**-0,60**	**-0,22**	**-1,55**	**-0,48**				
gas pipes HDPE high recycling	*direct fuels*	*2,29*									*0,51*	*0,50*	
	substituted fuels	*-0,24*		*-3,83*	*-1,91*	*-0,64*							
	direct & subst. fuels incl. precomb.			-2,41	-0,71	-0,28	0,40	2,72	0,84				
	substituted material production			-1,71	-21,34	-17,86	-0,32	-2,06	0,00	-0,04			0,02
gas pipes HDPE high recycling	**Total**			**-4,12**	**-22,05**	**-18,15**	**0,08**	**0,65**	**0,84**	**-0,04**			**0,02**
small drain and sewer p. PP	*direct fuels*	*0,33*									*0,35*	*0,07*	
	substituted fuels	*-1,05*		*-2,17*	*-1,09*	*-0,36*							
	direct & subst. fuels incl. precomb.			-2,63	-1,27	-0,61	-0,14	-1,04	-0,32				
	substituted material production			-0,18	-3,42	-2,02	-0,02	-0,24	0,00	0,00			0,01
small drain and sewer p. PP	**Total**			**-2,81**	**-4,69**	**-2,62**	**-0,17**	**-1,28**	**-0,32**	**0,00**			**0,01**
small drain and sewer p. PVC	*direct fuels*	*0,07*									*0,34*		
	substituted fuels	*-0,65*		*-1,26*	*-0,63*	*-0,21*							
	direct & subst. fuels incl. precomb.			-1,63	-0,69	-0,39	-0,12	-0,83	-0,26				
	substituted material production			-0,23	-1,40	-1,93	-0,09	-1,10	-0,05	-0,01			-0,11
small drain and sewer p. PVC	**Total**			**-1,87**	**-2,08**	**-2,32**	**-0,20**	**-1,93**	**-0,30**	**-0,01**			**-0,11**
conduit pipes PVC zero recycling	*direct fuels*	*0,00*									*0,32*		
	substituted fuels	*-0,73*		*-1,14*	*-0,57*	*-0,19*							
	direct & subst. fuels incl. precomb.			-1,61	-0,68	-0,40	-0,14	-1,02	-0,32				
	substituted material production												
conduit pipes PVC zero recycling	**Total**			**-1,61**	**-0,68**	**-0,40**	**-0,14**	**-1,02**	**-0,32**				

Table 51: Database for waste management of plastic pipes: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg or available waste, base case.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
small drain and sewer p. Steel low rec	*direct fuels*	*0,53*				*0,04*					*0,09*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,36	0,29	0,17	0,11	0,73	0,23				
	substituted material production			-1,49	-1,02	-0,84	-0,25		-0,52	-0,03			-0,04
small drain and sewer p. Steel low rec	**Total**			**-1,13**	**-0,73**	**-0,67**	**-0,14**	**0,73**	**-0,29**	**-0,03**			**-0,04**
conduit pipes Steel zero recycling	*direct fuels*										*0,08*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,09	0,00	0,00	0,00	0,00				
	substituted material production												
conduit pipes Steel zero recycling	**Total**			**0,00**	**0,09**	**0,00**	**0,00**	**0,00**	**0,00**				
gas pipes Steel high recycling	*direct fuels*	*0,59*				*0,04*					*0,10*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,40	0,33	0,19	0,12	0,82	0,25				
	substituted material production			-1,49	-1,02	-0,84	-0,25		-0,52	-0,03			-0,04
gas pipes Steel high recycling	**Total**			**-1,09**	**-0,69**	**-0,65**	**-0,13**	**0,82**	**-0,27**	**-0,03**			**-0,04**
small drain and sewer p. Aluminium	*direct fuels*	*0,31*			*0,22*	*0,83*					*0,09*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,21	0,48	1,05	0,06	0,43	0,13				
	substituted material production			-5,02	-10,13	-1,89	-8,35	-6,33	0,00	-0,03			0,03
small drain and sewer p. Aluminium	**Total**			**-4,82**	**-9,66**	**-0,84**	**-8,28**	**-5,90**	**0,13**	**-0,03**			**0,03**
small drinking water pipes Copper	*direct fuels*	*0,74*				*0,05*					*0,09*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,50	0,37	0,24	0,15	1,02	0,32				
	substituted material production			-0,94	-2,48	-2,41	-1,74		-0,58	-0,13			-0,04
small drinking water pipes Copper	**Total**			**-0,44**	**-2,11**	**-2,17**	**-1,60**	**1,02**	**-0,26**	**-0,13**			**-0,04**
small drain and sewer p. Fibrecement	*direct fuels*										*0,08*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,08	0,00	0,00	0,00	0,00				
	substituted material production												
small drain and sewer p. Fibrecement	**Total**			**0,00**	**0,08**	**0,00**	**0,00**	**0,00**	**0,00**				

Table 52: Database for waste management of pipes made of other materials: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg of available waste, base case.

		CO2	CH4	N2O
		mg	mg	mg
small drain and sewer p. HDPE low re	emissions from electr./steam/fuels	-357.941	-601	1
	CO2 from incinerated waste	625.079		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-131.095	-730	0
small drain and sewer p. HDPE low re	**Total**	**136.044**	**-1.332**	**1**
conduit pipes HDPE zero recycling	emissions from electr./steam/fuels	-383.976	-657	1
	CO2 from incinerated waste	628.571		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
conduit pipes HDPE zero recycling	**Total**	**244.596**	**-657**	**1**
gas pipes HDPE high recycling	emissions from electr./steam/fuels	-201.731	-269	0
	CO2 from incinerated waste	604.127		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-917.664	-5.111	0
gas pipes HDPE high recycling	**Total**	**-515.268**	**-5.380**	**0**
small drain and sewer p. PP	emissions from electr./steam/fuels	-389.755	-654	1
	CO2 from incinerated waste	625.079		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-136.847	-619	0
small drain and sewer p. PP	**Total**	**98.477**	**-1.274**	**1**
small drain and sewer p. PVC	emissions from electr./steam/fuels	-240.936	-412	2
	CO2 from incinerated waste	273.433		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-104.527	-369	0
small drain and sewer p. PVC	**Total**	**-72.030**	**-781**	**2**
conduit pipes PVC zero recycling	emissions from electr./steam/fuels	-244.524	-422	2
	CO2 from incinerated waste	282.051		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
conduit pipes PVC zero recycling	**Total**	**37.527**	**-422**	**2**

Table 53: Database for waste management of plastic pipes: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg of available waste, base case.

		CO2	CH4	N2O
		mg	mg	mg
small drain and sewer p. Steel low rec	emissions from electr./steam/fuels	83.501	152	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-249.090	-544	-7
small drain and sewer p. Steel low rec	**Total**	**-165.589**	**-392**	**-6**
conduit pipes Steel zero recycling	emissions from electr./steam/fuels	6.483	8	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions			
conduit pipes Steel zero recycling	**Total**	**6.483**	**8**	**1**
gas pipes Steel high recycling	emissions from electr./steam/fuels	93.343	170	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-249.090	-544	-7
gas pipes Steel high recycling	**Total**	**-155.747**	**-374**	**-6**
small drain and sewer p. Aluminium	emissions from electr./steam/fuels	118.932	239	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-1.293.408	-2.986	-3
small drain and sewer p. Aluminium	**Total**	**-1.174.476**	**-2.747**	**-2**
small drinking water pipes Copper	emissions from electr./steam/fuels	113.729	209	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-469.253	-533	-69
small drinking water pipes Copper	**Total**	**-355.523**	**-325**	**-68**
small drain and sewer p. Fibrecement	emissions from electr./steam/fuels	6.174	8	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions			
small drain and sewer p. Fibrecement	**Total**	**6.174**	**8**	**1**

Table 54: Database for waste management of pipes made of other materials: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg of available waste, base case.

4.3 Building: Other case studies

4.3.1 Insulation

The real market of insulation materials and products shows a wide variety, especially regarding insulation properties, thickness, mechanical characteristics, resistance to humidity, etc. In this study it is necessary to reduce the complex reality to a simple comparison of a few examples.

Two different application sectors have been distinguished in this study: insulation with a low demand of mechanical strength and insulation with a high demand of mechanical strength (e.g. insulation of cellar walls on the outside of the building, i.e. underground). In the first application sector, EPS and PUR are compared with mineral wool. To cover the second application sector, XPS and PUR are compared with foamglass.

On the German market of insulation materials, 95,6 % are covered by EPS, PUR, XPS, mineral wool and foamglass [Gesamtverband Dämmstoffindustrie, 1996]. Other insulation materials are therefore not considered in this study.

4.3.1.1 Market share of EPS, XPS and PUR

According to PlasticsEurope [1997], the total mass of plastics used for insulation in the building sector in 1995 was composed of 44,4 % PUR, 42,1 % EPS and 13,4 % XPS. More recent market data was not available.

For this study it was assumed that 40 % of the total mass is used for “rigid insulation applications” (see above), that is 26 % of the total volume of plastics insulation (all XPS and part of PUR). This assumption is considered to be a realistic figure, but it is critical for the result of the case study (see table below).

"Rigid insulation share"		Result
%-volume	%-mass	Mill GJ/a
20%	30%	-14
26%	**40%**	**-0,3**
32%	50%	15

Table 55: Result of the case study “insulation materials” in Mill GJ saved energy by plastics insulation per year, compared to the alternative materials, depending on the assumption of the share of total plastics insulation used for “rigid insulation applications”, meaning that substitution would have to be done by foamglass.

4.3.1.2 Mass ratios

Data on the density and the lambda-value of insulation materials are taken from:

- EPS, PUR and XPS: VKE [2004].
- Mineral wool sheet (for similar applications as for EPS or PUR sheet): Austrian insulation material producer [GUA 2000].
- Foamglass sheet: Foamglass [1992].

The functional unit for further calculations is defined by the insulating capacity of an EPS plate with a thickness of 10 cm. The following table shows theoretical thicknesses of the other materials to provide the same insulating capacity.

	Unit	**EPS**	**Mineral Wool**	**XPS**	**PUR**	**Foamglas**
Density	kg/m3	17,5	50,0	31,5	45,0	115,0
Lambda-value	W/mK	0,0375	0,0330	0,0325	0,0235	0,0540
Thickness for FU	m	0,100	0,088	0,087	0,063	0,144

Table 56: Basic data on insulation materials used for this study. “FU” = functional unit.

Based on the substitution model described above (a mix of EPS and PUR is mineral wool of the same insulating capacity; a mix of XPS and PUR is substituting foamglass of the same insulating capacity), the following mass ratios were deducted:

Table of mass ratios	**Market share plastics**	**Plastics total**	XPS	EPS	PUR	**Altern. mat. - Total**	Foamglass	Mineral wool
Insulation	3,76%	**1,00**	0,13	0,42	0,44	3,47	2,31	1,16

Table 57: Mass ratios for insulation materials used in this study.

4.3.1.3 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- EPS and XPS: total energy demand from VKE [2004]; for split into fuels and for calculation of emissions, the same proportions are assumed as in "PS expandable" from the PlasticsEurope inventories.
- PUR: PlasticsEurope inventory for "PUR rigid foam"
- Mineral wool sheet: total energy demand from IBO [1999]. Data in this study is mostly taken from ETH & EMPA [1996] and Kohler & Klingele [1995]. To split the total energy demand into fuels and to calculate emissions, the same proportions are assumed as in ETH & EMPA [1996] (average proportions of the four kinds of glass described in the study). It is assumed that precombustion energy is included in all data, although this might not be correct for some parts of the total energy demand. CO_2 emissions coming from raw materials used (lime, dolomite, soda) are included in the data used, but their contribution is just 2,7 % of the total CO_2 emissions.
- Foamglass sheet: total energy demand from Foamglass [1992]; for split into fuels and for calculation of emissions, the same proportions are assumed as in ETH & EMPA [1996] (average proportions of the four kinds of glass described in the study).

Material	**Product**	**Total energy demand MJ/kg**	coal MJ/kg	oil MJ/kg	gas MJ/kg	hydro MJ/kg	nuclear MJ/kg	lignite MJ/kg	wood / biomass MJ/kg	other MJ/kg
XPS	insulation	**82,22**	4,61	24,04	50,72	0,15	2,25	0,77	0,02	-0,33
EPS	insulation	**93,83**	5,26	27,43	57,88	0,17	2,57	0,88	0,02	-0,38
PUR	rigid foam	**104,61**	11,32	31,66	49,55	0,68	7,50	2,30	0,42	1,17
Foamglas	insulation	**23,51**	2,27	13,40	3,60	0,78	3,32	0,14	0,00	0,00
Mineral wool	insulation	**32,71**	3,12	18,46	4,97	1,38	4,58	0,20	0,00	0,00

Material	**Product**	CO_2 mg/kg	CH_4 mg/kg	N_2O mg/kg
XPS	insulation	2.591.891	9.410	0,1
EPS	insulation	2.957.758	10.738	0,1
PUR	rigid foam	3.924.185	19.618	18,0
Foamglas	insulation	1.127.033	1.460	3,5
Mineral wool	insulation	1.568.000	2.031	4,9

Table 58: Energy demand and emissions of the production phase of pipes used in this calculation model.

4.3.1.4 Energy and emissions of use phase

The functional unit of the comparison of different insulation materials is based theoretical sheets with different thicknesses, but the same insulating capacity. Therefore no difference in heating energy has to be considered as an effect of the use phase.

An effect considered is the escape of blowing agents from plastic foams over time. In Western Europe, mostly pentane is used as a blowing agent. Besides pentane, also CO2 and HCFC's are used, the latter constantly decreasing (the use of HCFC's for insulation foams is prohibited in the European Union since January 1st 2004 according to diective EG 2037/2000 with the last amendment on March 3rd, 2004).

In this study, only the effects of pentane as a blowing agent are calculated. The average pentane content is approx. 6 % of the total foam mass. The GWP of pentane is 3, compared to CO_2 and based on a time frame of 100 years. It is assumed that 90 % of the pentane used will escape over time, leading to 0,16 kg of CO_2-equivalents per kg foam. The average CO_2 emissions from the production phase of EPS, XPS and PUR are 3,3 kg CO_2 per kg foam. Therefore the additional GHG emissions of the use phase are about 5 % of the CO_2 emissions of the production phase. This amount has been included in the data of the production phase.

4.3.1.5 Energy and emissions of waste phase

In the waste management phase it is assumed that "rigid insulation" applications, i.e. mainly insulation used underground, will stay underground. Therefore only 60% of plastics insulation and all of mineral wool is considered as available waste.

Further on it is assumed for the base case of waste management, that only 10 % of insulation material is sorted out in mechanical sorting plants for building rubble for energy recovery, the rest is going to landfill. In the future case, 70 % are assumed to be sorted out for energy recovery.

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The resulting values used for waste from insulation material in this calculation model are shown in chapter 4.3.4.1.

4.3.2 Flooring

PVC and Linoleum cover about 90 % of the total market of flexible floor covering ([Gerflor 2004]; synthetic rubber and polyolefin flooring are the rest). Tiles, wooden flooring and carpets are very different in their properties and function and are rather used in other application sectors. Therefore these materials have not been included in the scope of this study.

4.3.2.1 Mass ratios

The share of mineral filling material in PVC flooring varies between 20 % and 65 % [GUA 2002]. The composition according to Umweltbundesamt [1998], used for this study, seems to be a realistic weighted average of the market of PVC flooring: 50 % mineral fillers, 17 % plasticizers and additives, 33 % PVC.

Masses of flooring materials used in this study: PVC flooring: 3,8 kg/m^2, Linoleum flooring: 3,45 kg/m^2 [Umweltbundesamt 1998]. On the level of products, the mass ratio table (see Table 6 and Table 7) would therefore show “1” for the plastic product and 3,45 / 3,8 = 0,908 for the alternative product.

Data in the “production database” of this calculation model is given per kg product. To get results per kg pure plastics (later these results are multiplied with pure plastic masses, not with product masses in Western Europe), the energy per kg (plastic) product has to be divided by the plastics share in the product:

(Energy / kg product) / (kg plastics / kg product) = energy / kg plastics

In the calculations for this study, the factor described above is included in the mass ratios used. Therefore both values given above are multiplied with 1/0,333 leading to a factor of 3,00 for PVC flooring and 2,73 for Linoleum flooring.

4.3.2.2 Energy and emissions of production phase

The study published by Umweltbundesamt [1998] contains detailed data for PVC and Linoleum flooring, and the values only refer to the production phase. On the other hand, only one example for each flooring material was analysed, and sources and reliability of data is not always clear.

Another study was carried out by Fraunhofer IVV institute and published by ERFMI, the European Resilient Flooring Manufacturers’ Institute [ERFMI 1998]. It is a very comprehensive study. Many different types of flooring were analysed (e.g. 19 different types of PVC flooring), and a peer review confirmed reliability of data. On the other hand, the results are only presented in aggregated form, and include also effects of the waste management phase. Additionally data for specific mass of the flooring materials is not presented in the report. Therefore transformation of energy data per m^2 to data per kg material is only possible with specific mass data from other sources.

To compare data for PVC, the average conditions of the ERFMI study were imitated by the calculation model used in this study (40 % PVC content, 20% softener, 40 % mineral fillers; no recycling, 25 % MSWI and 75 % landfill). It turned out that the values of the studies for PVC are quite comparable (with Umweltbundesamt showing an energy demand 5 % higher than ERFMI). Therefore for the calculations in this study the more detailed data of Umweltbundesamt were used.

For Linoleum, the data in ERFMI is about 30 % higher than in Umweltbundesamt. At the same time the absolute amount of renewable energy is higher in Umweltbundesamt than in ERFMI. Therefore the data of Umweltbundesamt were corrected: The total energy was increased by 25 %, and all of the increase was split between oil, gas and coal. The resulting energy demand is still 5 % lower than in ERFMI, and the share of renewable energy becomes 46 % compared to 41 % in ERFMI. Thus the estimated adaptation of Linoleum data was kept conservative from the perspective of plastic in all aspects.

GHG emissions from the production of Linoleum flooring are calculated by multiplying fuels with the emission factors described in chapter 3.3.

Material	**Product**	**Total energy demand**	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	other
		MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg
PVC	floor covering	**45,99**	6,53	11,27	14,58	0,87	9,02	3,41	0,00	0,31
Linoleum	floor covering	**36,00**	3,81	0,25	10,61	0,26	2,83	1,50	16,64	0,10

Material	**Product**	CO_2	CH_4	N_2O
		mg/kg	mg/kg	mg/kg
PVC	floor covering	1.591.068	2.543	208,7
Linoleum	floor covering	991.504	2.170	2,6

Table 59: Energy demand and emissions of the production phase of flooring materials used in this calculation model.

4.3.2.3 Energy and emissions of use phase

No effect in the use phase is assumed in this study:

The flooring material analysed in this study has similar cleaning properties (for effects due to flooring with different cleaning properties see GUA [2002]). Therefore no difference in the energy needed for cleaning is assumed.

Further on the same lifetime was assumed for the flooring materials. All studies mentioned so far assume the same lifetime for PVC and Linoleum. Usually the lifetime is not determined by the technical properties, but by the change in the optical impression of the surface, which is linked to cleaning properties.

4.3.2.4 Energy and emissions of waste phase

Beside the assumptions for the distribution of waste masses to recycling, energy recovery and landfill (see chapter 3.4.2) it is assumed in this study that Linoleum in landfills contributes to CH_4 emissions. This was also assumed in the study of ERFMI.

A specific value for CH_4 emissions per kg Linoleum during a time frame of e.g. 50 years in a landfill was not available. Therefore this value has been assumed in such a way that the resulting total GHG emissions of Linoleum showed the same relation to the total GHG emissions of PVC flooring as in the ERFMI study. It turned out that the value chosen in this way is about 50 % of the specific emission factor for wood in landfills.

The resulting figures used for the waste management phase are presented in chapter 4.3.4.1.

4.3.3 Window frames

4.3.3.1 Mass ratios

Figure 3 shows the market shares of the 3 main types of windows. Data were taken from Eurowindoor (www.window.de) and refer to 2000. The sector “Aluminium, Steel, combinations” was treated like aluminium, as aluminium windows are the major part of this sector. Furthermore, no sufficient data on steel windows were available; additionally consistent eco-balance data for the production phase were only available for the three main materials PVC, wood and aluminium.

The market share of materials beside PVC, expressed in percent of total non-plastics window frames, is therefore 50,2 % for wood and 49,8 % for aluminium.

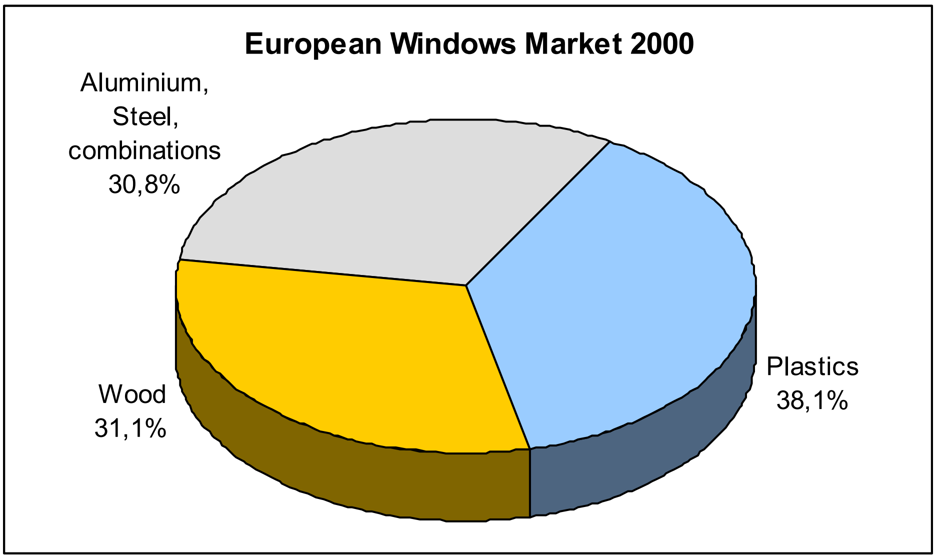

Figure 3: European Windows Market (Eurowindoor)

For the selection of data needed for the following calculations, four studies on window frames were available: EMPA [1996], Umweltbundesamt [1998], IKP [1998] and TU Wien

[1998]. These studies are based on different assumptions about the properties of the window frames investigated. The following table gives an overview on these assumptions:

Data source		UBA 1998	UBA 1998	UBA 1998	EMPA 1996	EMPA 1996	EMPA 1996
Material		PVC	wood	aluminium	PVC	wood	aluminium
Lifetime	a	40	40	75	30	30	30
Gross frame area	m2	0,530	0,555	0,456	0,887	0,917	0,644
Net frame area	m2	0,530	0,555	0,456	0,488	0,489	0,000
Height	m	1,5	1,5	1,5	1,65	1,65	1,65
Width	m	1	1	1	1,3	1,3	1,3
Mass main material	kg	16,4	15,6	13,03	25,57	19,7	27,5
Share additiva	%	20%	0%	0%	20%	0%	0%
Mass steel	kg	5,1	0	0	14,53	0,0	0,0
Mass window profile	kg	21,5	15,6	13,03	40,1	19,7	27,5
K-value frame	W/m2.K	1,96	1,45	2,8	1,5	1,5	1,9

Data source		IKP 1998	IKP 1998	IKP 1998	TU Wien 1997	TU Wien 1997	TU Wien 1997
Material		PVC	wood	aluminium	PVC	wood	aluminium
Lifetime	a	40	40	40	40...60	30...50	40...80
Gross frame area	m2	0,455	0,455	0,455	0	0	0
Net frame area	m2	0,455	0,455	0,455	0,455	0,455	0,455
Height	m	1,48	1,48	1,48	0,25	0,25	0,25
Width	m	1,23	1,23	1,23	0,25	0,25	0,25
Mass main material	kg	14,6	14,965	15,682	Total: 5,95	4,97	3,55
Share additiva	%	22%	0%	0%	0	0	0
Mass steel	kg	9,6	0	0	???	0	0
Mass window profile	kg	24,2	14,965	15,682	0	4,97	3,55
K-value frame	W/m2.K	1,8	1,8	1,8	1,8	1,8	1,8

Table 60: Comparison of data on window frames in four different studies.

In this study the masses of window frames are taken from Umweltbundesamt [1998]. For the calculation of mass ratios, also assumptions regarding the lifetime of window frame materials are necessary. The studies of EMPA [1996] and IKP [1998] assume the same lifetime for all window frame materials. In Umweltbundesamt [1998] 40 years are assumed for PVC and wood, but 75 years for aluminium. In TU Wien [1997] 40 – 60 years are assumed for PVC, 30 – 50 for wood and 40 – 80 for aluminium. In this study, the same lifetime is assumed for PVC and wood window frames and a 50 % longer lifetime is assumed for aluminium (e.g.: 40 / 40 / 60 years).

On the level of products (1 kg PVC window frame, including additives and steel), these data lead to mass ratios of 0,36 for wood and 0,30 for aluminium, meaning that 1 kg PVC window frame would be substituted by an average mix of 0,36 kg wood and 0,30 kg aluminium (calculated from mass of functional unit of aluminium x market share x lifetime factor / mass of functional unit of PVC; etc.).

The PVC window frame itself consists of 61 % pure PVC, 15 % additives and 24 % steel to improve rigidity [Umweltbundesamt 1998]. Like in the case study for flooring, the values for production, use and waste management will be calculated per kg product, while the multiplying factor to produce absolute results for Western Europe will be the pure PVC mass used for window frames. Therefore both, the value “1” for the PVC product and the mass ratios for wood and aluminium are multiplied with 1/0,61 (see chapter 3.2). The resulting data used in this study are shown in the table below.

Table of mass ratios	**Market share plastics**	**Plastics total**	PVC	**Altern. mat. - Total**	Aluminium	**Wood**, textile, etc.
Windows	2,16%	**1,63**	1,63	0,92	0,33	0,59

Table 61: Mass ratios for window frames used in this study

4.3.3.2 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- PVC window frame and wood window frame: Umweltbundesamt [1998]
- Aluminium window frame: It was not possible to use the data presented Umweltbundesamt [1998], because in this study obviously a high recycling share is assumed within the production of aluminium, but the recycling share is not mentioned. It also was not possible to get the information directly from the authors. As an estimate, data for aluminium packaging film were corrected regarding processing energy: From the values for aluminium film, the energy for "aluminium sheet rolling" ([Ecoinvent 2004], multiplied with 2 because we assumed that the aluminium film for packaging is thinner than the product of "sheet rolling) was subtracted and the energy for "aluminium extrusion" [Ecoinvent 2004] was added.

Material	**Product**	**Total energy demand** **MJ/kg**	coal MJ/kg	oil MJ/kg	gas MJ/kg	hydro MJ/kg	nuclear MJ/kg	lignite MJ/kg	wood / biomass MJ/kg	other MJ/kg
PVC modified + steel	window	**52,91**	9,88	14,62	19,76	0,70	6,79	0,97	0,00	0,19
Aluminium	profile	**190,56**	30,52	58,32	16,08	47,71	35,18	2,00	0,76	0,00
Wood	window	**35,33**	4,09	0,22	1,01	0,56	5,91	3,13	20,18	0,23

Material	**Product**	CO_2 mg/kg	CH_4 mg/kg	N_2O mg/kg
PVC modified + steel	window	1.877.660	2.982	429,3
Aluminium	profile	8.076.900	17.806	43,8
Wood	window	631.189	1.214	0,1

Table 62: Energy demand and emissions of the production phase of window frame materials used in this calculation model.

4.3.3.3 Energy and emissions of use phase

The main effect in the use phase of a window is the heat escaping through it, which must be replaced by heating. Only the window frames are considered, the glazing does not depend to the frame material and can therefore be regarded as the same in all cases, so there is no difference between the frame materials.

To calculate how much heat escapes through the window frame, the k-value and the frame area are important variables, as well as the climate, which determines the necessity of heating inside a building and is given in heating degree days.

The k-value gives information on the insulating properties of the window frame. The lower the k-value, the less heat goes through it. k-values depend on the material as well as to the quality and type of construction. According to Spindler [1999], PVC and wood windows should be considered to have the same k-value, since there are better PVC windows than wood windows and better wood windows than PVC windows as well. In EMPA [1998], PVC and wood are also calculated with the same k-value. The following table gives an overview on possible k-values mentioned in different studies:

possible k-values in W/m2.K	**pvc**	**wood**	**aluminium**	**source**
standard in CH	1,5	1,5	2,0	EMPA 1996
standard in D	1,5...1,8	1,5	2,6...2,8	EMPA 1996
	1,5	1,5	1,9	EMPA 1997
	1,5...1,96	1,45	2,0...2,8	UBA 1998
2-chamber-profile	1,7...1,75			UBA 1998
3-chamber-profil usual today)	1,5...1,6			UBA 1998
depends on material...		1,5...2,5		IKP 1998
depends on material...		1,5...2,5		TU Wien 1998
this study	**1,5**	**1,5**	**1,9**	

Table 63: Comparison of possible k-values mentioned in different studies..

For calculations, IKP [1986] and TU Wien [1997] have assumed the same k-value for all three materials (1,8 W/m^2.K). Umweltbundesamt [1998] has assumed 1,96 for PVC, 1,45 for wood and 2,8 for aluminium. EMPA [1996] has assumed 1,5 for PVC and for wood and 1,9 for aluminium. To calculate the effects in use in this study, the same k-values as in EMPA [1996] are used.

The frame area of different windows can be different for different window frames, but this is not related to the properties of a certain material. The net frame area also depends to the way a window is built in. Therefore, in this study the same frame area is used for all types of windows. The average value of the window frames analysed in Umweltbundesamt [1998] is used, which is 0,514 m^2.

“Heating degree days” are taken from the German city Mannheim (2.600 K.d/a). This value is used as an estimate for the average heating degree days in Western Europe.

The resulting heating losses per kg window frame material are 322 MJ/kg PVC, 444 MJ/kg wood and 1.010 MJ/kg aluminium. The same effects given per kg PVC frame: 322 MJ/kg PVC for PVC and wood frames, 407 MJ/kg PVC for the aluminium frame.

Further on it is assumed that the average heating energy is produced by 50 % from extra light fuel oil and by 50 % from natural gas in Western Europe. Finally precombustion energy is added and GHG emissions are calculated by multiplying fuels with the emission factors described in chapter 3.3.

This procedure finally leads to an average advantage in the use phase of 80,5 MJ/kg PVC window frame. That means: If 1 kg of PVC window frame is substituted by wood and aluminium, extra energy of about 80 MJ is needed to compensate for the lower k-value of aluminium frame during the total lifetime of the (substituted) PVC window frame.

4.3.3.4 Energy and emissions of waste phase

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The resulting values used for window frame materials in this calculation model are shown in chapter 4.3.4.1.

4.3.4 Data for all case studies in the sector

4.3.4.1 Energy and emissions of waste phase

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The tables below show the resulting database per kg of building material. For insulation material the data is given per kg *available* waste.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
insulation plastics	*direct fuels*	*0,03*									*2,62*		
	substituted fuels	*-1,15*		*-1,84*	*-0,92*	*-0,31*							
	direct & subst. fuels incl. precomb.			-2,56	1,25	-0,63	-0,22	-1,56	-0,49				
	substituted material production												
insulation plastics	**Total**			**-2,56**	**1,25**	**-0,63**	**-0,22**	**-1,56**	**-0,49**				
flooring PVC	*direct fuels*	*0,04*									*0,49*		
	substituted fuels	*-0,32*		*-0,63*	*-0,31*	*-0,10*							
	direct & subst. fuels incl. precomb.			-0,81	0,01	-0,19	-0,06	-0,41	-0,13				
	substituted material production			-0,12	-0,70	-0,97	-0,04	-0,55	-0,02	-0,01			-0,06
flooring PVC	**Total**			**-0,93**	**-0,69**	**-1,16**	**-0,10**	**-0,96**	**-0,15**	**-0,01**			**-0,06**
windows PVC	*direct fuels*	*0,30*				*0,02*					*0,47*		
	substituted fuels	*-0,45*		*-1,47*	*-0,74*	*-0,25*							
	direct & subst. fuels incl. precomb.			-1,56	-0,53	-0,31	-0,03	-0,24	-0,08				
	substituted material production			-0,89	-1,55	-1,87	-0,18	-0,84	-0,28	-0,02			-0,10
windows PVC	**Total**			**-2,44**	**-2,08**	**-2,18**	**-0,21**	**-1,08**	**-0,36**	**-0,02**			**-0,10**

Table 64: Database for waste management of insulation material, flooring and window frames made of plastics: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
insulation (Mineral wool)	*direct fuels*										*2,18*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,01	2,42	0,01	0,00	0,03	0,01				
	substituted material production												
insulation (Mineral wool)	**Total**			**0,01**	**2,42**	**0,01**	**0,00**	**0,03**	**0,01**				
flooring (Linoleum)	*direct fuels*	*0,00*									*0,51*		
	substituted fuels	*-0,31*		*-0,49*	*-0,25*	*-0,08*							
	direct & subst. fuels incl. precomb.			-0,69	0,11	-0,17	-0,06	-0,44	-0,14				
	substituted material production												
flooring (Linoleum)	**Total**			**-0,69**	**0,11**	**-0,17**	**-0,06**	**-0,44**	**-0,14**				
windows Aluminium	*direct fuels*	*0,42*			*0,29*	*1,13*					*0,33*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,29	0,88	1,42	0,08	0,58	0,18				
	substituted material production			-6,78	-13,68	-2,55	-11,27	-8,55	0,00	-0,04			0,03
windows Aluminium	**Total**			**-6,50**	**-12,80**	**-1,14**	**-11,18**	**-7,96**	**0,18**	**-0,04**			**0,03**
windows wood	*direct fuels*	*0,00*									*0,51*		
	substituted fuels	*-0,41*		*-0,64*	*-0,32*	*-0,11*							
	direct & subst. fuels incl. precomb.			-0,91	-0,02	-0,22	-0,08	-0,57	-0,18				
	substituted material production												
windows wood	**Total**			**-0,91**	**-0,02**	**-0,22**	**-0,08**	**-0,57**	**-0,18**				

Table 65: Database for waste management of insulation material, flooring and window frames made of other materials: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	**mg**	**mg**
insulation plastics	emissions from electr./steam/fuels	-218.339	-458	23
	CO2 from incinerated waste	643.077		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
insulation plastics	**Total**	**424.738**	**-458**	**23**
flooring PVC	emissions from electr./steam/fuels	-94.415	-173	4
	CO2 from incinerated waste	136.578		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-52.210	-185	0
flooring PVC	**Total**	**-10.048**	**-358**	**4**
windows PVC	emissions from electr./steam/fuels	-201.191	-335	3
	CO2 from incinerated waste	246.033		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-198.323	-540	-3
windows PVC	**Total**	**-153.481**	**-876**	**-1**

Table 66: Database for waste management of insulation material, flooring and window frames made of plastics: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
insulation (Mineral wool)	emissions from electr./steam/fuels	176.400	220	21
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions			
insulation (Mineral wool)	**Total**	**176.400**	**220**	**21**
flooring (Linoleum)	emissions from electr./steam/fuels	-75.910	-145	4
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)		74.239	
	subst. production emissions			
flooring (Linoleum)	**Total**	**-75.910**	**74.094**	**4**
windows Aluminium	emissions from electr./steam/fuels	178.006	344	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-1.746.101	-4.031	-5
windows Aluminium	**Total**	**-1.568.094**	**-3.687**	**-1**
windows wood	emissions from electr./steam/fuels	-111.410	-205	4
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)		148.479	
	subst. production emissions			
windows wood	**Total**	**-111.410**	**148.273**	**4**

Table 67: Database for waste management of insulation material, flooring and window frames made of other materials: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

4.4 Electric and electronic sector

4.4.1 Housing of electric and electronic appliances

4.4.1.1 Market share of plastic products and split into polymers

According to PlasticsEurope [2001] the total consumption of plastics for E&E equipment in 2000 was 1.483 kt. The polymers suitable for housings (ABS-ASA-SAN, PS, PP, PVC, PC) cover 78 % of the total mass. In this study it is assumed that 1/3 of the total consumption of these polymers are used to produce housings in the E&E sector, that is equivalent to 26 % of all plastics used for E&E equipment or 14 % of all plastics used in the E&E sector (including cables and electrical equipment).

Polymers used in E&E equipment	**1.000 t**
ABS-ASA-SAN	496
PS	287
PP	266
PU	125
EP	55
PVC	54
PC	53
UP	49
PA	45
POM	26
PBT-PET	19
PE	8
Total	**1.483**

Table 68: Plastics used for E&E equipment in 2000 in Western Europe

The calculation model in this study considers ABS, PS and PP as polymers for housings (these cover 91 % of the possible polymers for housings). The market share is directly derived from the figures above.

4.4.1.2 Mass ratios

Non plastic housings are very rare on the market today, therefore possible mass ratios for alternative materials can only be derived from selected examples, where data is available.

The mass ratios for steel and wood are obtained from the example of TV housings. Data regarding masses of TV housings were taken from the following sources:

- For housings made of steel: written information from a large German company producing TV-sets
- For housings made of wood: written information from different Austrian electric- & electronic equipment dismantling firms

Mass ratios of housings of TV-sets (used for calculation)				
material	**dimension**	**total mass ca. [kg]**	**average mass per material [kg]**	**mass ratios (plastic =1)**
plastic (HIPS, NORYL)	29´´ (73,7cm) picture tube	6,58	5,79	1,0
plastic (ABS or SB)	4:3 standard TV-set, 72cm screen diagonal	5,00		
wood	see table TV-set - materials plastic and wood (used for calculation)			1,5
special steel	29´´ (73,7cm) picture tube	18,40	14,95	2,6
special steel	4:3 standard TV-set, 72cm screen diagonal	11,50		

TV-set housings made of plastics and wood (used for calculation)			
material	**average mass per piece [kg]**	**mass ratios (plastic =1)**	**comments**
plastic	8,6	1,0	average mass from dismantling tests (information from E&E dismantling firm A)
wood	14,0	1,6	average mass from dismantling tests (information from E&E dismantling firm A)
plastic	5,0	1,0	average mass from dismantling tests (information from E&E dismantling firm B)
wood	7,5	1,5	average mass from dismantling tests (information from E&E dismantling firm B)
plastic	2,6	1,0	average mass from dismantling tests (information from E&E dismantling firm C)
wood	4,0	1,5	average mass from dismantling tests (information from E&E dismantling firm C)

TV-set housings made of plastics and wood (not used for calculation)			
material	**average mass per material ca. [kg]**	**mass ratios (plastic =1)**	**comments**
plastic	2-2,5	1,0	estimation from E&E dismantling firm D
wood	4-5	2,0	estimation from E&E dismantling firm D

Table 69: Data on the mass of TV housings made of different materials

The mass ratio of housings made of plastics compared to aluminium was already investigated in the study of GUA [2000]. An ABS and an aluminium multi-purpose industrial housing were selected for comparison. They are used for e.g. sensitive electronic controls, to mount boards or to simply assemble some cables. Their measurements are: length 115 cm x width 65 cm x height 55 cm. The ABS housing has got a mass of 142 g, the aluminium housing weighs 310 g (source: a German producer of industrial components).

Beside steel, aluminium and wood it is assumed that also synthetic rubber could be an alternative for plastics (electrically insulating like plastics; easier to shape as wood and steel), but only for small housings (not enough rigidity for bigger housings). The mass ratio for rubber is derived from values on tensile strength, an important parameter to describe mechanical properties of materials. For PS tensile strength is approximately 50 Mpa (45 – 65), for rubber it is approximately 25 Mpa. Therefore a mass ratio of 2 is assumed for the comparison of plastics and rubber.

The mass ratios used in this study for the mix of alternative materials substituting one average kg of plastic housing are calculated by multiplying the mass ratios for every single material with the market share of the materials. Non plastic housings are very rare on the market today, therefore no market data is available that could describe the mix of materials, if all plastic housings were substituted by other materials. In this study 25 % are assumed as market share for each of the possible alternative materials.

	Mass ratio for every single material	Assumed market share of alternative materials	Mass ratios used in this study
Steel	**2,60**	25%	**0,65**
Aluminium	**2,18**	25%	**0,55**
Wood	**1,50**	25%	**0,38**
Rubber	**2,00**	25%	**0,50**

Table 70: Mass ratios for E&E housings used in this study

4.4.1.3 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- Data for PP and PS (energy for processing included) are taken from the inventories published by PlasticsEurope.
- For ABS housings, the energy needed to produce ABS granulate (PlasticsEurope inventories) is combined with the processing energy for injection moulding (PlasticsEurope inventories).
- Steel: For the production of steel, different inventories are available depending on the kind and quality of the respective product. Data from Ecoinvent [2004] show an energy demand of 17 – 20 MJ/kg for low alloyed steel, 22 MJ/kg for cast iron and 68 MJ/kg for high alloyed steel 18/8 (18 % Cr, 8 % Ni; “stainless steel”). In this study it is assumed that the steel products are usually painted or zinc coated (exception: some houseware applications). Therefore the data for primary production are based on a rather low steel quality. For this study, generally the inventory of cast iron was used.

  To protect the surface against oxidation, zinc coating is assumed (data for the energy needed to paint the surface was not available). Therefore, data for producing cast iron, for sheet rolling and for zinc coating are combined to estimate the energy demand of producing steel housings [Ecoinvent 2004].
- Data to produce aluminium housings were not available. As an estimate, data for aluminium packaging film were corrected regarding processing energy: From the values for aluminium film, the energy for “aluminium sheet rolling” ([Ecoinvent 2004], multiplied with 2 because we assumed that the aluminium film for packaging is thinner than the product of “sheet rolling) was subtracted and then the energy for “aluminium sheet rolling” was added.

- Wood: It was assumed that the energy demand to produce wood housings is similar than the energy needed to produce wooden window frames [Umweltbundesamt 1988].
- Rubber: [Ecoinvent 2004].

Material	**Product**	**Total energy demand** **MJ/kg**	coal MJ/kg	oil MJ/kg	gas MJ/kg	hydro MJ/kg	nuclear MJ/kg	lignite MJ/kg	wood / biomass MJ/kg	other MJ/kg
PP	injection moulding	**118,84**	12,58	45,74	48,79	0,81	9,82	0,07	0,86	0,19
PS	high impact	**91,81**	2,05	35,54	52,40	0,06	1,87	0,11	0,01	-0,24
ABS	injection moulding	**140,84**	13,71	36,88	78,27	0,64	8,52	1,71	0,83	0,28
Steel, zinc coated	sheet	**38,42**	9,81	8,79	12,90	2,81	0,00	3,59	0,25	0,28
Aluminium	sheet	**184,77**	29,35	57,79	14,04	47,23	35,18	1,03	0,22	-0,07
Wood	window	**35,33**	4,09	0,22	1,01	0,56	5,91	3,13	20,18	0,23
Rubber	"at plant"	**100,60**	5,49	62,93	24,18	2,34	0,00	4,43	0,89	0,34

Material	**Product**	CO_2 mg/kg	CH_4 mg/kg	N_2O mg/kg
PP	injection moulding	4.013.497	19.990	0,1
PS	high impact	2.737.168	9.247	0,1
ABS	injection moulding	5.468.178	22.566	0,2
Steel, zinc coated	sheet	2.287.569	4.490	63,1
Aluminium	sheet	7.702.800	17.295	32,6
Wood	window	631.189	1.214	0,1
Rubber	"at plant"	3.035.400	13.431	140,3

Table 71: Energy demand and emissions of the production phase of housing materials used in this calculation model.

4.4.1.4 Energy and emissions of use phase

In this study, no relevant effects of the use phase on energy demand or GHG emissions due to different housing materials were identified. Effects in use are therefore not included in the calculations.

4.4.1.5 Energy and emissions of waste phase

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The resulting values used for window frame materials in this calculation model are shown in chapter 4.4.3.1.

4.4.2 Insulation of refrigerators and freezers

4.4.2.1 Market share of plastic products

Data on the consumption of large household appliances in Western Europe [AJI Europe 2003] state for the consumption of plastics for refrigerators in Western Europe a mass of 220.000 t in 2000. A breakdown of plastics used in refrigerators by polymer is given by ZVEI [2003]. Therefore the total mass of PUR used for refrigerators in Western Europe is assumed with 55.000 t.

4.4.2.2 Mass ratios

For the comparison of different insulation materials for refrigerators and freezers, this study assumes that the inner and outer volume of the appliances stay the same, reflecting a given available space and a constant service rendered regarding volume.

Therefore, the volume available for insulation is the same in both scenarios. As a result, the mass ratio can be derived directly from the density of the materials, which is 45 kg/m^3 for PUR [VKE 2004] and 50 kg/m^3 for a mineral wool sheet produced for similar applications as a PUR sheet (Austrian insulation material producer [GUA 2000]). The resulting mass ratio is 1,11.

4.4.2.3 Energy and emissions of production phase

See chapter 4.3.1.3.

4.4.2.4 Energy and emissions of use phase

As described above, the same thickness of insulation is assumed for PUR and mineral wool. Due to the higher lambda-value of mineral wool, a refrigerator with mineral wool insulation needs more electrical power to keep the same temperature than the refrigerator with PUR insulation. This effect in use is calculated in this study.

In the following calculation, three categories are distinguished: refrigerators, freezers, and combined appliances. For all three categories, data about the average inner volume and the annual energy demand were available [Konsument 1996 - 2003]. In 1994, about 4,6 Mill refrigerators, 1,7 Mill freezers and 2,3 Mill combined appliances were put on the market [AEA 1994].

Based on this data, a schematic model for refrigerators and freezers was developed: For each of the inner volumes given, a surface area was estimated. The thickness of the insulation was assumed in a way that the resulting energy demand matched with the values taken from literature.

The formula to calculate the energy needed is

Q = A x lambda / d x CDS, where

A ... surface area in m2

lambda ... thermal conductivity(?) in W/K.m

d ... thickness of insulation in m

CDS ... cooling degree seconds in Ks

with CDS = $\int (T_o-T_i).dt$

Additionally the value "cooling degree seconds divided by the temperature difference (outside minus inside)" should be equal for all three categories.

Lambda-values were assumed to be 0,0235 for PUR and 0,033 for mineral wool (see Table 56). Temperature differences were assumed to be 18°C for the refrigerator and 40°C for the freezer. The resulting insulation thicknesses in this theoretical model were 6,5 cm for the refrigerator and 7,8 cm for the freezer.

The weighted average energy demand of the three categories analysed with PUR as insulation (6,4 kg PUR per average piece) was 887 MJ_{el}/a according to the values given in Konsument [1996 - 2003]. The same calculation with mineral wool led to an average energy demand of 1.245 MJ_{el}/a. The difference of 358 MJ_{el}/a was multiplied with a lifetime of 10 years and divided by the mass of PUR per average piece, leading to 1.840 MJ saved primary resources per kg PUR.

4.4.2.5 Energy and emissions of waste phase

For the base case of waste management it is assumed that 30 % of refrigerators are collected separately (PUR foam is then recovered after a shredder process and used for energy recovery), the rest is treated as average residual waste. In the future case, 70 % are assumed to be collected separately.

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The resulting values used for insulation material in this calculation model are shown in chapter 4.4.3.1.

4.4.3 Data for all case studies in the sector

4.4.3.1 Energy and emissions of waste phase

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The tables below show the resulting database per kg of plastics in the E&E sector.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
housing PP	*direct fuels*	*0,01*									*0,73*		
	substituted fuels	*-0,98*		*-1,63*	*-0,81*	*-0,27*							
	direct & subst. fuels incl. precomb.			-2,26	-0,65	-0,56	-0,19	-1,38	-0,43				
	substituted material production												
housing PP	**Total**			**-2,26**	**-0,65**	**-0,56**	**-0,19**	**-1,38**	**-0,43**				
housing PS	*direct fuels*	*0,01*									*0,73*		
	substituted fuels	*-1,02*		*-1,68*	*-0,84*	*-0,28*							
	direct & subst. fuels incl. precomb.			-2,33	-0,70	-0,57	-0,20	-1,43	-0,44				
	substituted material production												
housing PS	**Total**			**-2,33**	**-0,70**	**-0,57**	**-0,20**	**-1,43**	**-0,44**				
housing ABS	*direct fuels*	*0,07*									*0,71*		
	substituted fuels	*-0,86*		*-1,81*	*-0,90*	*-0,30*							
	direct & subst. fuels incl. precomb.			-2,32	-0,73	-0,55	-0,16	-1,13	-0,35				
	substituted material production			-0,43	-4,28	-6,97	-0,01	-0,21	-0,21	0,00			0,00
housing ABS	**Total**			**-2,74**	**-5,02**	**-7,52**	**-0,17**	**-1,34**	**-0,56**	**0,00**			**0,00**
insulation in refrig. PUR	*direct fuels*	*0,00*									*0,73*		
	substituted fuels	*-0,58*		*-0,96*	*-0,48*	*-0,16*							
	direct & subst. fuels incl. precomb.			-1,33	-0,05	-0,33	-0,11	-0,81	-0,25				
	substituted material production												
insulation in refrig. PUR	**Total**			**-1,33**	**-0,05**	**-0,33**	**-0,11**	**-0,81**	**-0,25**				
housing Steel	*direct fuels*	*0,79*				*0,06*					*0,25*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,54	0,57	0,26	0,16	1,09	0,34				
	substituted material production			-2,23	-1,53	-1,26	-0,37		-0,78	-0,05			-0,06
housing Steel	**Total**			**-1,70**	**-0,96**	**-1,00**	**-0,21**	**1,09**	**-0,44**	**-0,05**			**-0,06**
housing Aluminium	*direct fuels*	*0,14*			*0,10*	*0,38*					*0,26*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,10	0,46	0,47	0,03	0,20	0,06				
	substituted material production			-2,26	-4,56	-0,85	-3,76	-2,85	0,00	-0,01			0,01
housing Aluminium	**Total**			**-2,16**	**-4,10**	**-0,38**	**-3,73**	**-2,65**	**0,06**	**-0,01**			**0,01**
housing wood	*direct fuels*	*0,00*									*0,73*		
	substituted fuels	*-0,34*		*-0,56*	*-0,28*	*-0,09*							
	direct & subst. fuels incl. precomb.			-0,78	0,30	-0,19	-0,07	-0,47	-0,15				
	substituted material production												
housing wood	**Total**			**-0,78**	**0,30**	**-0,19**	**-0,07**	**-0,47**	**-0,15**				
housing (rubber)	*direct fuels*	*0,00*									*0,73*		
	substituted fuels	*-0,36*		*-0,59*	*-0,29*	*-0,10*							
	direct & subst. fuels incl. precomb.			-0,82	0,28	-0,20	-0,07	-0,49	-0,15				
	substituted material production												
housing (rubber)	**Total**			**-0,82**	**0,28**	**-0,20**	**-0,07**	**-0,49**	**-0,15**				

Table 72: Database for waste management of plastics and other materials used in the E&E sector: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case. Data for mineral wool: see Mineral wool in the building sector (chapter 4.3.4.1).

		CO2	CH4	N2O
		mg	mg	mg
housing PP	emissions from electr./steam/fuels	-319.513	-562	5
	CO2 from incinerated waste	534.286		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
housing PP	**Total**	**214.772**	**-562**	**5**
housing PS	emissions from electr./steam/fuels	-331.421	-582	5
	CO2 from incinerated waste	575.385		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
housing PS	**Total**	**243.964**	**-582**	**5**
housing ABS	emissions from electr./steam/fuels	-322.248	-558	5
	CO2 from incinerated waste	536.640		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-403.238	-1.311	0
housing ABS	**Total**	**-188.847**	**-1.869**	**5**
insulation in refrig. PUR	emissions from electr./steam/fuels	-164.069	-301	6
	CO2 from incinerated waste	405.167		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
insulation in refrig. PUR	**Total**	**241.098**	**-301**	**6**
housing Steel	emissions from electr./steam/fuels	134.653	240	2
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-373.635	-815	-11
housing Steel	**Total**	**-238.982**	**-576**	**-8**
housing Aluminium	emissions from electr./steam/fuels	71.629	130	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-582.034	-1.344	-2
housing Aluminium	**Total**	**-510.404**	**-1.214**	**1**
housing wood	emissions from electr./steam/fuels	-72.184	-147	6
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)		154.047	
	subst. production emissions			
housing wood	**Total**	**-72.184**	**153.900**	**6**
housing (rubber)	emissions from electr./steam/fuels	-78.195	-157	6
	CO2 from incinerated waste	342.833		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
housing (rubber)	**Total**	**264.638**	**-157**	**6**

Table 73: Database for waste management of plastics and other materials used in the E&E sector: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case. Data for mineral wool: see Mineral wool in the building sector (chapter 4.3.4.1).

4.5 Automotive sector: Plastic parts and alternative materials used in cars

4.5.1 Data for all case studies in the sector

4.5.1.1 Mass ratios

Several studies have compared specific plastic parts used in cars with components made of other materials. Only two studies tried to analyse all plastic parts used in cars: Franklin

[1991] and Heyde & Nürrenbach [1999] (Fraunhofer institute IVV). Data of the latter investigation was used for this study. The values are based on a detailed list of plastic parts used in 4 different cars (Volkswagen and Audi), each one being an example of lower class, lower medium class, upper medium class and upper class.

The detailed lists of plastic parts and their possible substitutes (provided by Audi AG, Germany) are aggregated to three application sectors of plastic parts in cars: "Exterior and cockpit" (bumper, lights housing, ventilation grid, instrument panel, housings), "under the hood" (fuel tank, containers, housings, pipes) and "other components" (mainly seats, panelling on doors and inside, hub caps, etc.). In every application sector, the three most important polymer types have been considered in this calculation model; they cover at least 87 % of the total substitutable plastic mass in each application sector.

As already described in chapter 2.2.1, only 45 % of the total mass of plastics used in cars can be substituted by other materials without changing design and function decisively. The following tables and calculations refer to the substitutable plastic parts only. Alternative materials are steel, aluminium, glass, and rubber hair (the latter for substitution of PUR in seats).

The following table shows the mass ratios for the aggregated application sectors, i.e. the mass of alternative materials needed to substitute one average kg of plastics in this application sector.

The aggregated mass ratio for the total car is 1,48. Therefore the total mass of substitutable plastic parts (75 kg per average car) could be substituted by a total mass of 111 kg of alternative materials.

Table of mass ratios	**Market share plastics**	**Plastics total**	HDPE	PP	PMMA	PA-GF (first line), ABS (other)	PUR	**Altern. mat. - Total**	Steel	Aluminium	Glass	Rubber
Under the hood	1,45%	**1,00**	0,38	0,37		0,25		1,48	1,14	0,34		
Exterior & cockpit	0,96%	**1,00**		0,75	0,10	0,15		1,57	1,07	0,28	0,23	
Other automotive parts	0,77%	**1,00**		0,12		0,13	0,74	1,36	0,31	0,10	0,15	0,80

Table 74: Aggregated mass ratios for automotive parts used in this study

4.5.1.2 Discussion of mass ratios used in different studies

In this chapter different sources for mass ratios derived from a direct comparison of plastics with alternative materials are compared.

1) Mass ratios used in this study [Heyde & Nürrenbach 1999]:

The average mass ratios used in the IVV study are:

- Steel / plastics: 1,5
- Aluminium / Plastics: 1,2 for profiles, 1,5 for pressure die-casting
- Glass / PC: 2,2
- Rubber hair / PUR: 1,2

Values for single components can vary between:

- Steel / plastics: 1,24 – 4,00
- Aluminium / Plastics: 1,24 – 3,00
- Glass / PC: 2,15 – 4,00

2) Mass ratios from an analysis by Mavel [2004]:

The following table shows data for several components used in cars, made of plastics, steel or aluminium. The weighted average of the steel values (for the components investigated, not for all plastic parts which would be substituted by steel) is similar compared to the value used in the study of IVV.

For plastic parts substituted by aluminium, the data of Mavel shows mass ratios between 1,7 and 0,73. The weighted average is 0,96, which is considerably smaller than the value used in this study. Sensitivity analysis will show how the results change, if the mass ratios for aluminium are divided by 1,5 in this calculation model.

	Plastics Average mass [g]	Steel Average mass [g]	mass ratio Fe/Plastics
Fuel tank	7.700	10.000	1,30
Fenders	1.200	3.100	2,58
Hatchback	9.300	12.000	1,29
Front hood	10.000	14.000	1,40
Weighted average			**1,39**

	Plastics Average mass [g]	Aluminium Average mass [g]	mass ratio Al/Plastics
Cylinder head cover	1.300	2.000	1,54
Air intake manifold	2.200	3.700	1,68
Hatchback	9.300	8.800	0,95
Front hood	10.000	7.300	0,73
Weighted average			**0,96**

Table 75: Mass ratios for certain automotive parts based on data from Mavel [2004]

3) Mass ratios used in GUA [2000]

In GUA [2000], data received from the automotive industry lead to the mass ratios of 1,66 for a comparison of bumpers (plastics/steel) and to 1,30 for a comparison of fuel tanks (plastics/steel).

4.5.1.3 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- Data for PP, PMMA, PA-GF (glass fibre) and PUR (energy for processing included) are taken from the inventories published by PlasticsEurope.
- For ABS and HDPE injection moulded products, the energy needed to produce ABS and HDPE granulate (PlasticsEurope inventories) is combined with the processing energy for injection moulding (PlasticsEurope inventories).
- Steel (see chapter 4.4.1.3): To protect the surface against oxidation, zinc coating is assumed (data for the energy needed to paint the surface was not available). Therefore, data for producing cast iron, for sheet rolling and for zinc coating are combined [Ecoinvent 2004].
- Data to produce aluminium components were not available. As an estimate, data for aluminium packaging film were corrected regarding processing energy: From the values for aluminium film, the energy for “aluminium sheet rolling” ([Ecoinvent 2004], multiplied with 2 because we assumed that the aluminium film for packaging is thinner than the product of “sheet rolling) was subtracted and then the energy for “aluminium sheet rolling” was added.
- White glass: ETH & EMPA [1996]
- Rubber: [Ecoinvent 2004].

Material	Product	Total energy demand	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	other
		MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg
PP	injection moulding	**118,84**	12,58	45,74	48,79	0,81	9,82	0,07	0,86	0,19
HDPE	injection moulding	**122,77**	13,41	41,13	55,40	1,09	10,52	0,07	0,90	0,26
PUR	flexible foam	**104,33**	10,84	33,14	44,89	0,85	8,67	3,58	0,77	1,60
PMMA	sheet	**129,11**	5,99	38,80	72,78	0,78	7,94	2,41	0,06	0,35
PA-GF (Nylon 66, glass filled)		**108,28**	14,59	24,39	58,23	0,43	6,92	2,21	0,09	1,41
ABS	injection moulding	**140,84**	13,71	36,88	78,27	0,64	8,52	1,71	0,83	0,28
Steel, zinc coated	sheet	**38,42**	9,81	8,79	12,90	2,81	0,00	3,59	0,25	0,28
Aluminium	sheet	**184,77**	29,35	57,79	14,04	47,23	35,18	1,03	0,22	-0,07
Glass	white	**12,74**	0,93	8,34	0,57	0,59	2,18	0,12	0,00	0,00
Rubber	"at plant"	**100,60**	5,49	62,93	24,18	2,34	0,00	4,43	0,89	0,34

Material	Product	CO_2	CH_4	N_2O
		mg/kg	mg/kg	mg/kg
PP	injection moulding	4.013.497	19.990	0,1
HDPE	injection moulding	3.942.477	21.359	0,1
PUR	flexible foam	4.064.710	17.570	33,0
PMMA	sheet	6.900.000	24.000	0,0
PA-GF (Nylon 66, glass filled)		5.442.066	21.975	2.233,6
ABS	injection moulding	5.468.178	22.566	0,2
Steel, zinc coated	sheet	2.287.569	4.490	63,1
Aluminium	sheet	7.702.800	17.295	32,6
Glass	white	748.000	781	2,0
Rubber	"at plant"	3.035.400	13.431	140,3

Table 76: Energy demand and emissions of the production phase of automotive parts used in this calculation model.

4.5.1.4 Energy and emissions of use phase

The use of plastic parts in cars leads to less mass and therefore reduces fuel consumption during the whole use phase. Studies give various figures about the extent of the mass-related fuel savings (see Table 77). For this study, 0,35 l per 100 km and 100 kg is chosen [IVV 1999 = Heyde & Nürrenbach 1999].

Source	**l/(100 km. 100 kg)**	**range**
IVV 1999	0,35	
Elf Atochem	0,5	
APME (150.000 km)	0,7	
EUCAR 1997	0,38	0,19…0,6
EUCAR 1997		0,26…0,37
Eberle 1998		0,34…0,48
Eberle 1998		0,29…0,33
Saur Nyb	0,35	0,35…0,85
Franklin	0,26	
This study	**0,35**	

Table 77: Change in fuel consumption due to more or less mass of a car

For the total distance driven in the in the lifetime of a car, 150.000 km are assumed. 75 kg of plastics therefore cause a fuel consumption of 394 litres in the total lifetime, 111 kg of alternative materials needed for substitution would cause a fuel consumption of 583 litres. The fuel saved due to the use of plastic products is 189 litres or 2,52 litres per kg plastics. With a density of 0,84 kg/l for diesel and an upper heating value of 45,5 MJ/kg, this is transformed to approximately 96 MJ/kg plastics. Finally precombustion energy is added, leading to saved primary fuels of 110 MJ/kg plastics.

4.5.1.5 Energy and emissions of waste phase

For the calculation of waste management effects, certain shares of the materials are assumed to be recovered for recycling (for plastic parts, rubber and glass by dismantling, for other materials by automatic sorting in the shredder process):

Recycling rates base case	HDPE	PP	PE-X, PMMA	PA-GF, ABS	PUR	Steel	Aluminium	Glass	Rubber
under the hood	5%	5%		5%		80%	20%		
exterior and cockpit		40%	40%	40%		80%	20%	0%	
other automotive parts		0%		0%	0%	80%	20%	0%	20%

Recycling rates future case	HDPE	PP	PMMA	PA-GF, ABS	PUR	Steel	Aluminium	Glass	Rubber
under the hood	10%	10%		10%		90%	40%		
exterior and cockpit		50%	50%	50%		90%	40%	20%	
other automotive parts		0%		0%	10%	90%	40%	20%	40%

Table 78: Assumed recycling rates in base case and future case.

The rest of plastics goes through the shredder process into "light shredder residues". In this model these residues are used for energy recovery in a fluidised bed combustion plant.

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The tables below show the resulting database per kg of plastics in the E&E sector.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
under the hood HDPE	*direct fuels*	*0,16*									*1,02*	*0,04*	
	substituted fuels	*-0,49*		*-1,22*	*-0,61*	*-0,20*							
	direct & subst. fuels incl. precomb.			-1,43	0,22	-0,32	-0,07	-0,48	-0,15				
	substituted material production			-0,12	-1,52	-1,28	-0,02	-0,15	0,00	0,00			0,00
under the hood HDPE	**Total**			**-1,55**	**-1,30**	**-1,60**	**-0,09**	**-0,63**	**-0,15**	**0,00**			**0,00**
under the hood PP	*direct fuels*	*0,16*									*1,02*	*0,04*	
	substituted fuels	*-0,50*		*-1,23*	*-0,62*	*-0,21*							
	direct & subst. fuels incl. precomb.			-1,44	0,21	-0,33	-0,07	-0,49	-0,15				
	substituted material production			-0,09	-1,71	-1,01	-0,01	-0,12	0,00	0,00			0,00
under the hood PP	**Total**			**-1,53**	**-1,50**	**-1,33**	**-0,08**	**-0,60**	**-0,15**	**0,00**			**0,00**
under the hood PA-GF	*direct fuels*	*0,16*									*1,02*	*0,04*	
	substituted fuels	*-0,49*		*-1,22*	*-0,61*	*-0,20*							
	direct & subst. fuels incl. precomb.			-1,43	0,22	-0,32	-0,07	-0,48	-0,15				
	substituted material production			-0,41	-1,71	-1,01	-0,01	-0,12	0,00	0,00			0,00
under the hood PA-GF	**Total**			**-1,84**	**-1,49**	**-1,33**	**-0,08**	**-0,60**	**-0,15**	**0,00**			**0,00**
exterior and cockpit PP	*direct fuels*	*1,23*									*0,86*	*0,29*	
	substituted fuels	*-0,30*		*-2,16*	*-1,08*	*-0,36*							
	direct & subst. fuels incl. precomb.			-1,51	0,15	-0,21	0,18	1,22	0,38				
	substituted material production			-0,71	-1,71	-1,01	-0,01	-0,12	0,00	0,00			0,00
exterior and cockpit PP	**Total**			**-2,22**	**-1,56**	**-1,22**	**0,17**	**1,11**	**0,38**	**0,00**			**0,00**
exterior and cockpit PMMA	*direct fuels*	*1,23*									*0,86*	*0,29*	
	substituted fuels	*-0,30*		*-2,14*	*-1,07*	*-0,36*							
	direct & subst. fuels incl. precomb.			-1,49	0,17	-0,21	0,18	1,23	0,38				
	substituted material production			-0,88	-11,55	-20,47	-0,11	-1,47	-0,59	-0,01		-0,14	0,11
exterior and cockpit PMMA	**Total**			**-2,37**	**-11,38**	**-20,68**	**0,07**	**-0,24**	**-0,21**	**-0,01**		**-0,14**	**0,11**
exterior and cockpit ABS	*direct fuels*	*1,23*									*0,86*	*0,29*	
	substituted fuels	*-0,30*		*-2,14*	*-1,07*	*-0,36*							
	direct & subst. fuels incl. precomb.			-1,49	0,17	-0,21	0,18	1,23	0,38				
	substituted material production			-1,08	-10,82	-17,62	-0,04	-0,53	-0,53	0,00			0,01
exterior and cockpit ABS	**Total**			**-2,57**	**-10,65**	**-17,83**	**0,15**	**0,70**	**-0,15**	**0,00**			**0,01**
other automotive parts other	*direct fuels*	*0,01*									*1,04*		
	substituted fuels	*-0,53*		*-1,10*	*-0,55*	*-0,18*							
	direct & subst. fuels incl. precomb.			-1,43	0,22	-0,34	-0,10	-0,73	-0,23				
	substituted material production												
other automotive parts other	**Total**			**-1,43**	**0,22**	**-0,34**	**-0,10**	**-0,73**	**-0,23**				
other automotive parts PUR	*direct fuels*	*0,00*									*1,04*		
	substituted fuels	*-0,31*		*-0,65*	*-0,32*	*-0,11*							
	direct & subst. fuels incl. precomb.			-0,84	0,61	-0,20	-0,06	-0,42	-0,13				
	substituted material production												
other automotive parts PUR	**Total**			**-0,84**	**0,61**	**-0,20**	**-0,06**	**-0,42**	**-0,13**				

Table 79: Database for waste management of plastics used in the automotive sector: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		electricity MJ	steam MJ	coal MJ	oil MJ	gas MJ	hydro MJ	nuclear MJ	lignite MJ	wood / biomass MJ	petrol/diesel MJ	fuel oil extra light MJ	other MJ
under the hood Steel	*direct fuels*	*2,12*				*0,16*					*0,34*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			1,43	1,16	0,69	0,42	2,92	0,91				
	substituted material production			-5,95	-4,09	-3,35	-0,99		-2,08	-0,13			-0,16
under the hood Steel	**Total**			**-4,52**	**-2,93**	**-2,66**	**-0,57**	**2,92**	**-1,17**	**-0,13**			**-0,16**
under the hood Aluminium	*direct fuels*	*0,28*			*0,20*	*0,75*					*0,34*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,19	0,72	0,94	0,06	0,39	0,12				
	substituted material production			-4,52	-9,12	-1,70	-7,51	-5,70	0,00	-0,03			0,02
under the hood Aluminium	**Total**			**-4,33**	**-8,40**	**-0,76**	**-7,45**	**-5,31**	**0,12**	**-0,03**			**0,02**
exterior and cockpit Glass	*direct fuels*										*0,19*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,21	0,00	0,00	0,00	0,00				
	substituted material production			1,82	-1,14	3,22	-0,27	-0,26	-0,05	0,00			
exterior and cockpit Glass	**Total**			**1,83**	**-0,93**	**3,22**	**-0,27**	**-0,26**	**-0,05**	**0,00**			
other automotive parts Rubber	*direct fuels*	*0,10*									*0,95*		
	substituted fuels	*-0,15*		*-0,50*	*-0,25*	*-0,08*							
	direct & subst. fuels incl. precomb.			-0,52	0,70	-0,11	-0,01	-0,07	-0,02				
	substituted material production			-0,66	-7,53	-2,89	-0,28		-0,53	-0,11			-0,04
other automotive parts Rubber	**Total**			**-1,18**	**-6,83**	**-3,00**	**-0,29**	**-0,07**	**-0,55**	**-0,11**			**-0,04**

Table 80: Database for waste management of other materials used in the automotive sector: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
under the hood HDPE	emissions from electr./steam/fuels	-142.937	-267	8
	CO2 from incinerated waste	321.729		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-65.547	-365	0
under the hood HDPE	**Total**	**113.245**	**-632**	**8**
under the hood PP	emissions from electr./steam/fuels	-145.199	-271	8
	CO2 from incinerated waste	321.729		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-68.424	-310	0
under the hood PP	**Total**	**108.107**	**-580**	**8**
under the hood PA-GF	emissions from electr./steam/fuels	-142.937	-267	8
	CO2 from incinerated waste	321.729		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-68.424	-310	0
under the hood PA-GF	**Total**	**110.369**	**-577**	**8**
exterior and cockpit PP	emissions from electr./steam/fuels	-99.914	-154	6
	CO2 from incinerated waste	373.835		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-68.424	-310	0
exterior and cockpit PP	**Total**	**205.497**	**-464**	**6**
exterior and cockpit PMMA	emissions from electr./steam/fuels	-96.672	-149	6
	CO2 from incinerated waste	373.835		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-1.809.508	-6.070	0
exterior and cockpit PMMA	**Total**	**-1.532.346**	**-6.219**	**6**
exterior and cockpit ABS	emissions from electr./steam/fuels	-96.672	-149	6
	CO2 from incinerated waste	373.835		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-1.018.706	-3.312	0
exterior and cockpit ABS	**Total**	**-741.544**	**-3.461**	**6**
other automotive parts other	emissions from electr./steam/fuels	-151.668	-287	9
	CO2 from incinerated waste	314.286		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
other automotive parts other	**Total**	**162.618**	**-287**	**9**
other automotive parts PUR	emissions from electr./steam/fuels	-54.702	-126	9
	CO2 from incinerated waste	238.333		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
other automotive parts PUR	**Total**	**183.632**	**-126**	**9**

Table 81: Database for waste management of plastics used in the automotive sector: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
under the hood Steel	emissions from electr./steam/fuels	333.731	608	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-996.360	-2.175	-29
under the hood Steel	**Total**	**-662.629**	**-1.567**	**-26**
under the hood Aluminium	emissions from electr./steam/fuels	129.034	242	4
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-1.164.067	-2.687	-3
under the hood Aluminium	**Total**	**-1.035.033**	**-2.445**	**0**
exterior and cockpit Glass	emissions from electr./steam/fuels	15.435	19	2
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	282.523	-487	-1
exterior and cockpit Glass	**Total**	**297.958**	**-468**	**1**
other automotive parts Rubber	emissions from electr./steam/fuels	-4.007	-34	9
	CO2 from incinerated waste	200.605		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-363.337	-1.608	-17
other automotive parts Rubber	**Total**	**-166.739**	**-1.641**	**-8**

Table 82: Database for waste management of other materials used in the automotive sector: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

4.6 Housewares

Plastics are used for a big number of different houseware applications. It turned out to be very difficult to define typical case studies to represent the housewares sector in this calculation model. Additionally no market data on the level of products or product groups are available. Therefore many assumptions had to be made in this sector. The weak database is also expressed by high values for the assumed uncertainties (see Table 110 and Table 111).

In this study keep fresh boxes and buckets are assumed to be typical plastic products in the sector of housewares. Additionally this section also includes a case study on waste bins, a product group for which good data on product masses is available. It is assumed that keep fresh boxes could somehow represent small houseware products; buckets could represent medium size and waste bins big products in the sector of housewares.

4.6.1 Data for all case studies in the sector

4.6.1.1 Market share of plastic products

To get market data regarding plastics used in the sector of housewares, AJI Europe and a market expert of one of the biggest producers of PE and PP were contacted. Market data was only available with regards to a polymer split (estimate for housewares: 360 kt PP, 275 kt HDPE and 100 kt LDPE). More specific data on the level of product groups was not available.

For this study it is assumed that keep fresh boxes could represent 30 % of the total market, buckets could represent 10 % and waste bins could represent another 10 % of the total market. The remaining 50 % of the total mass of houseware applications are not covered by the case studies of this report.

4.6.1.2 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- Data for PP and HDPE (energy for processing included) are taken from the inventories published by PlasticsEurope.
- Steel: If steel was used to substitute houseware plastics, it would often be stainless steel (68 MJ/kg; see chapter 4.4.1.3). Nevertheless the calculations below are once more based on the combination of data for producing cast iron (22 MJ/kg), for sheet rolling and for zinc coating [Ecoinvent 2004]. This inaccuracy favours the results for alternative materials; the simplification is therefore conservative from the perspective of plastics.
- Data to produce aluminium components were not available. As an estimate, data for aluminium packaging film were corrected regarding processing energy: From the values for aluminium film, the energy for “aluminium sheet rolling” ([Ecoinvent 2004], multiplied with 2 because we assumed that the aluminium film for packaging is thinner than the product of “sheet rolling) was subtracted and then the energy for “aluminium sheet rolling” was added.
- White glass: ETH & EMPA [1996]

Material	**Product**	**Total energy demand**	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	other
		MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg
PP	injection moulding	**118,84**	12,58	45,74	48,79	0,81	9,82	0,07	0,86	0,19
HDPE	pipe	**88,29**	4,44	51,11	26,72	1,05	4,13	0,23	0,45	0,16
Steel, zinc coated	sheet	**38,42**	9,81	8,79	12,90	2,81	0,00	3,59	0,25	0,28
Aluminium	sheet	**184,77**	29,35	57,79	14,04	47,23	35,18	1,03	0,22	-0,07
Glass	white	**12,74**	0,93	8,34	0,57	0,59	2,18	0,12	0,00	0,00

Material	**Product**	CO_2	CH_4	N_2O
		mg/kg	mg/kg	mg/kg
PP	injection moulding	4.013.497	19.990	0,1
HDPE	pipe	2.186.695	8.440	0,5
Steel, zinc coated	sheet	2.287.569	4.490	63,1
Aluminium	sheet	7.702.800	17.295	32,6
Glass	white	748.000	781	2,0

Table 83: Energy demand and emissions of the production phase of houseware products used in this calculation model. The data for “HDPE pipe” are used for the HDPE waste bin.

4.6.1.3 Energy and emissions of waste phase

In the "base case" of waste management, the following recycling shares have been assumed:

5 % for keep fresh boxes and buckets made of plastics

15 % for keep fresh boxes and buckets made of other materials

60 % for plastic waste bins and 70 % for steel waste bins.

In the "future case" of waste management, recycling shares are slightly raised:

15 % for buckets made of plastics

30 % for keep fresh boxes and buckets made of other materials

70 % for plastic waste bins and 80 % for steel waste bins.

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The tables below show the resulting database per kg of plastics in the E&E sector.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ
keep fresh boxes PP	*direct fuels*	*0,17*									*0,80*	*0,04*	
	substituted fuels	*-1,12*		*-2,01*	*-1,01*	*-0,34*							
	direct & subst. fuels incl. precomb.			-2,63	-0,79	-0,63	-0,19	-1,35	-0,42				
	substituted material production			-0,09	-1,71	-1,01	-0,01	-0,12	0,00	0,00			0,00
keep fresh boxes PP	**Total**			**-2,71**	**-2,50**	**-1,64**	**-0,20**	**-1,47**	**-0,42**	**0,00**			**0,00**
buckets PP	*direct fuels*	*0,16*									*0,80*	*0,04*	
	substituted fuels	*-1,12*		*-1,94*	*-0,97*	*-0,32*							
	direct & subst. fuels incl. precomb.			-2,56	-0,74	-0,62	-0,19	-1,36	-0,42				
	substituted material production			-0,09	-1,71	-1,01	-0,01	-0,12	0,00	0,00			0,00
buckets PP	**Total**			**-2,65**	**-2,46**	**-1,62**	**-0,20**	**-1,48**	**-0,42**	**0,00**			**0,00**
waste bins HDPE	*direct fuels*	*1,84*									*0,87*	*0,43*	
	substituted fuels	*-0,43*		*-2,95*	*-1,47*	*-0,49*							
	direct & subst. fuels incl. precomb.			-1,96	-0,03	-0,26	0,28	1,87	0,58				
	substituted material production			-1,47	-18,29	-15,31	-0,27	-1,77	0,00	-0,04			0,02
waste bins HDPE	**Total**			**-3,43**	**-18,32**	**-15,57**	**0,00**	**0,10**	**0,58**	**-0,04**			**0,02**
keep fresh boxes Steel	*direct fuels*	*0,40*				*0,03*					*0,34*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,27	0,52	0,13	0,08	0,55	0,17				
	substituted material production			-1,12	-0,77	-0,63	-0,19		-0,39	-0,02			-0,03
keep fresh boxes Steel	**Total**			**-0,85**	**-0,25**	**-0,50**	**-0,11**	**0,55**	**-0,22**	**-0,02**			**-0,03**
keep fresh boxes Aluminium	*direct fuels*	*0,21*			*0,15*	*0,56*					*0,34*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,14	0,63	0,71	0,04	0,30	0,09				
	substituted material production			-3,39	-6,84	-1,28	-5,63	-4,27	0,00	-0,02			0,02
keep fresh boxes Aluminium	**Total**			**-3,25**	**-6,21**	**-0,57**	**-5,59**	**-3,98**	**0,09**	**-0,02**			**0,02**
keep fresh boxes Glass	*direct fuels*										*0,08*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,09	0,00	0,00	0,00	0,00				
	substituted material production			1,39	-0,87	2,45	-0,21	-0,20	-0,04	0,00			
keep fresh boxes Glass	**Total**			**1,39**	**-0,78**	**2,45**	**-0,21**	**-0,20**	**-0,04**	**0,00**			
waste bins Zinc coated iron	*direct fuels*	*1,75*				*0,14*					*0,30*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			1,18	0,98	0,58	0,35	2,41	0,75				
	substituted material production			-5,21	-3,58	-2,93	-0,86		-1,82	-0,11			-0,14
waste bins Zinc coated iron	**Total**			**-4,03**	**-2,60**	**-2,36**	**-0,52**	**2,41**	**-1,07**	**-0,11**			**-0,14**

Table 84: Database for waste management of plastics and other materials used in the E&E sector: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case. Data for mineral wool: see Mineral wool in the building sector (chapter 4.3.4.1).

		CO2	CH4	N2O
		mg	mg	mg
keep fresh boxes PP	emissions from electr./steam/fuels	-364.805	-635	5
	CO2 from incinerated waste	626.825		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-68.424	-310	0
keep fresh boxes PP	**Total**	**193.597**	**-945**	**5**
buckets PP	emissions from electr./steam/fuels	-355.515	-620	5
	CO2 from incinerated waste	619.474		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-68.424	-310	0
buckets PP	**Total**	**195.535**	**-930**	**5**
waste bins HDPE	emissions from electr./steam/fuels	-136.535	-198	5
	CO2 from incinerated waste	519.398		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-786.569	-4.381	0
waste bins HDPE	**Total**	**-403.705**	**-4.579**	**5**
keep fresh boxes Steel	emissions from electr./steam/fuels	84.698	142	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-186.818	-408	-5
keep fresh boxes Steel	**Total**	**-102.119**	**-266**	**-2**
keep fresh boxes Aluminium	emissions from electr./steam/fuels	103.207	190	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-873.050	-2.016	-2
keep fresh boxes Aluminium	**Total**	**-769.844**	**-1.826**	**1**
keep fresh boxes Glass	emissions from electr./steam/fuels	6.817	9	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	214.717	-370	-1
keep fresh boxes Glass	**Total**	**221.534**	**-362**	**0**
waste bins Zinc coated iron	emissions from electr./steam/fuels	276.389	503	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-871.815	-1.903	-25
waste bins Zinc coated iron	**Total**	**-595.426**	**-1.400**	**-23**

Table 85: Database for waste management of plastics and other materials used in the E&E sector: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case. Data for mineral wool: see Mineral wool in the building sector (chapter 4.3.4.1).

4.6.2 Keep fresh boxes

4.6.2.1 Mass ratios

Data on mass and volume of keep-fresh boxes were taken from the following sources:

- weighed out in different stores
- folders from different companies
- web-sites.

For the calculation of mass ratios we used keep-fresh boxes with a lid. The containers had different sizes and different volumes. Therefore an average mass referring to one litre was calculated. Keep-fresh boxes without a top were not used for the case study.

The mass ratios for alternative materials listed below were multiplied with assumed market shares of alternative materials, if plastic keep fresh boxes would be replaced: 35 % steel, 30 % aluminium, 35 % glass.

Keep-fresh boxes (used for calculation)								
material	**shape**	**volume [l]**	**mass - bottom part [g]**	**mass - top [g]**	**total mass ca. [g]**	**mass [g/l]**	**average mass per material [g/l]**	**mass ratios (plastic =1)**
plastic (PP)	rectangular	1,14	105	40	145	127	115	1,0
plastic (PP)	rectangular	1,78	160	40	200	112		
plastic (PP)	rectangular	1,92	120	45	165	86		
plastic (PP; top LDPE)	rectangular	1,30	125	75	200	154		
plastic (PETF; top PP)	round	0,46	32	11	43	93		
aluminium	round	1,48	138	44	182	123	123	1,1
sheet metal	round	1,25	141	46	187	150	135	1,2
sheet metal	round	2,00	165	75	240	120		
glass	round	0,50	450	370	820	1640	1045	9,1
glass	rectangular	0,53			760	1434		
glass	rectangular	1,20			1330	1108		
glass	round	1,40	720	580	1300	929		
glass	rectangular	1,40			1200	857		
glass	rectangular	1,90			1400	737		
glass	rectangular	2,50			1800	720		
glass	rectangular	2,80			2620	936		

Keep-fresh boxes (not used for calculation)					
material	**shape**	**volume [l]**	**mass - bottom part [g]**	**mass - top [g]**	**total mass ca. [g]**
plastic	round	0,25	28	no lid	28
plastic	round	1,00	169	no lid	169
sheet metal	round	0,25	49	no lid	49
glass	round	0,38	183	no lid	183
clay	rectangular	1,14			1600

Table 86: Mass ratios for keep fresh boxes used in this study

4.6.3 Buckets

4.6.3.1 Mass ratios

The calculation of mass ratios for buckets is related to round buckets for household or garden. The final mass ratios refer to a filling volume of one litre. Data for buckets were taken from the following sources:

- weighed out in different stores
- folders and written information from different companies
- web-sites.

buckets (used for calculation)						
material	**application sector**	**volume [l]**	**total weight ca. [g]**	**weight [g/l]**	**average weight per material [g/l]**	**weight ratios (plastic= 1)**
plastic (PP)	household/garden	12	275	23	23	1,0
steel (zinc coated)	household/garden	12	1000	83	82	3,6
steel (zinc coated)	household/garden	20	1600	80		

buckets (not used for calculation)			
material	**application sector**	**volume [l]**	**total weight ca. [g]**
plastic (PE - made of DSD material)	building/construction	12	450
wrought-iron (zinc coated)	agriculture	13,5	2100
special steel	dairy/gastronomy	10	1340

Table 87: Mass ratios for buckets used in this study

4.6.4 Waste bins

4.6.4.1 Mass ratios

Data on masses and filling volumes of garbage containers were taken from folders and written information from different companies. The final mass ratios refer to a filling volume of one litre.

waste bins (used for calculation)						
material	**shape**	**volume [l]**	**total mass [kg]**	**mass [kg/l]**	**average mass per material [kg/l]**	**mass ratios (plastic= 1)**
plastic (PE HD)	rectangular	120	11,3	0,094	0,077	1,0
plastic (PE HD)	rectangular	240	15,5	0,065		
plastic (PE HD)	rectangular	240	16	0,067		
plastic (PE LD)	rectangular	120	11	0,092		
plastic (PE LD)	rectangular	240	16	0,067		
steel (zinc coated)	rectangular	120	26	0,217	0,173	2,3
steel (zinc coated)	rectangular	240	31	0,129		

waste bins (not used for calculation)			
material	**shape**	**volume [l]**	**total mass [kg]**
plastic (PE LD)	round	35	2,7
plastic (PE LD)	round	50	3,2
steel (zinc coated)	round	35	8,5
steel (zinc coated)	round	50	9,5

Table 88: Mass ratios for waste bins used in this study

4.7 Furniture

4.7.1 Data for all case studies in the sector

4.7.1.1 Market share of plastic products

As in the sector of housewares, it was difficult to get market data and to define possible case studies for furniture. Data of AJI Europe [2003] differentiate the sector of furniture into the polymers used in 2002:

LDPE injection moulded	183
HDPE film	120
HDPE blow moulded	46
HDPE injection moulded	330
PP film	69
PP Injection Moulded	751
PP others	100
PVC film	105
PVC sheets thermoformed	335
PVC injection moulded	90
PVC others	65
PS injection moulded	265
PS others	153
PET film	60
ABS/SAN injection moulded	215
PMMA others	80
POM	38
PC	122
PA	141
PTFE, polyol, EVOH	121
Total amino moulded	557
Total epoxy adhesives	32
Total unsaturated polyester	156
Total PU foams	476
Total	**4.610**

Table 89: Polymers used in the sector of furniture. Values seem to be overestimated, as the total mass of 4.600 kt/a is equivalent to 12 % of the total consumption of plastic products in Western Europe. In chapter 2.1 the share of furniture was estimated with 4 % of the total market.

An expert for marketing of one of the biggest producers of PE and PP estimated that garden furniture represents the biggest part of plastics used for furniture. Another important product group are PUR foams, mainly used in mattresses.

In this study it is assumed that 35 % of the total mass of plastics used for furniture can be represented by the case study garden furniture and 15 % can be represented by the case study mattresses. The remaining 50 % of the total mass of furniture applications are not covered by the case studies of this report.

4.7.1.2 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- Data for PP and PUR (energy for processing included) are taken from the inventories published by PlasticsEurope.
- Steel (see chapter 4.4.1.3): To protect the surface against oxidation, zinc coating is assumed (data for the energy needed to paint the surface was not available). Therefore, data for producing cast iron, for sheet rolling and for zinc coating are combined [Ecoinvent 2004].
- Data to produce aluminium components were not available. As an estimate, data for aluminium packaging film were corrected regarding processing energy: From the values for aluminium film, the energy for “aluminium sheet rolling” ([Ecoinvent 2004], multiplied with 2 because we assumed that the aluminium film for packaging is thinner than the product of “sheet rolling) was subtracted and then the energy for “aluminium sheet rolling” was added.
- Wood: It was assumed that the energy demand to produce wood furniture is similar than the energy needed to produce wooden window frames [Umweltbundesamt 1988].
- Latex: [Ecoinvent 2004].

Material	**Product**	**Total energy demand**	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	other
		MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg	MJ/kg
PP	injection moulding	**118,84**	12,58	45,74	48,79	0,81	9,82	0,07	0,86	0,19
PUR	flexible foam	**104,33**	10,84	33,14	44,89	0,85	8,67	3,58	0,77	1,60
Steel, zinc coated	sheet	**38,42**	9,81	8,79	12,90	2,81	0,00	3,59	0,25	0,28
Aluminium	sheet	**184,77**	29,35	57,79	14,04	47,23	35,18	1,03	0,22	-0,07
Wood	window	**35,33**	4,09	0,22	1,01	0,56	5,91	3,13	20,18	0,23
Latex	at plant	**86,88**	1,89	39,67	44,85	0,20	0,00	0,21	0,05	0,00

Material	**Product**	CO_2	CH_4	N_2O
		mg/kg	mg/kg	mg/kg
PP	injection moulding	4.013.497	19.990	0,1
PUR	flexible foam	4.064.710	17.570	33,0
Steel, zinc coated	sheet	2.287.569	4.490	63,1
Aluminium	sheet	7.702.800	17.295	32,6
Wood	window	631.189	1.214	0,1
Latex	at plant	2.415.434	8.596	0,7

Table 90: Energy demand and emissions of the production phase of furniture products used in this calculation model.

4.7.1.3 Energy and emissions of waste phase

For the calculation of waste management effects, certain shares of the materials are assumed to be recycled:

Recycling rates base case	PP	PUR	Steel	Aluminium
garden furniture	5%		60%	15%
matresses		5%	5%	

Recycling rates future case	PP	PUR	Steel	Aluminium
garden furniture	20%		80%	40%
matresses		20%	20%	

Table 91: Assumed recycling rates in base case and future case.

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The tables below show the resulting database per kg of plastics in the sector of furniture.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**	**MJ**
garden furniture PP	*direct fuels*	*0,16*									*0,75*	*0,04*	
	substituted fuels	*-0,93*		*-1,73*	*-0,87*	*-0,29*							
	direct & subst. fuels incl. precomb.			-2,23	-0,59	-0,53	-0,15	-1,10	-0,34				
	substituted material production			-0,09	-1,71	-1,01	-0,01	-0,12	0,00	0,00			0,00
garden furniture PP	**Total**			**-2,32**	**-2,30**	**-1,54**	**-0,17**	**-1,22**	**-0,34**	**0,00**			**0,00**
matresses PUR	*direct fuels*	*0,04*									*1,57*		
	substituted fuels	*-0,55*		*-1,06*	*-0,53*	*-0,18*							
	direct & subst. fuels incl. precomb.			-1,38	0,83	-0,33	-0,10	-0,72	-0,22				
	substituted material production			-0,46	-1,42	-1,92	-0,04	-0,37	-0,15	-0,03			-0,07
matresses PUR	**Total**			**-1,85**	**-0,59**	**-2,25**	**-0,14**	**-1,09**	**-0,37**	**-0,03**			**-0,07**
garden furniture Steel	*direct fuels*	*1,59*				*0,12*					*0,34*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			1,07	0,96	0,51	0,31	2,19	0,68				
	substituted material production			-4,46	-3,07	-2,51	-0,74		-1,56	-0,10			-0,12
garden furniture Steel	**Total**			**-3,39**	**-2,10**	**-2,00**	**-0,43**	**2,19**	**-0,88**	**-0,10**			**-0,12**
garden furniture Aluminium	*direct fuels*	*0,21*			*0,15*	*0,56*					*0,29*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,14	0,57	0,71	0,04	0,29	0,09				
	substituted material production			-3,39	-6,84	-1,28	-5,63	-4,27	0,00	-0,02			0,02
garden furniture Aluminium	**Total**			**-3,25**	**-6,27**	**-0,57**	**-5,59**	**-3,98**	**0,09**	**-0,02**			**0,02**
garden furniture wood	*direct fuels*	*0,00*									*0,73*		
	substituted fuels	*-0,34*		*-0,56*	*-0,28*	*-0,09*							
	direct & subst. fuels incl. precomb.			-0,78	0,30	-0,19	-0,07	-0,47	-0,15				
	substituted material production												
garden furniture wood	**Total**			**-0,78**	**0,30**	**-0,19**	**-0,07**	**-0,47**	**-0,15**				
matresses Steel	*direct fuels*	*0,13*				*0,01*					*3,42*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,11	3,84	0,05	0,03	0,23	0,07				
	substituted material production			-0,37	-0,26	-0,21	-0,06		-0,13	-0,01			-0,01
matresses Steel	**Total**			**-0,26**	**3,58**	**-0,16**	**-0,03**	**0,23**	**-0,06**	**-0,01**			**-0,01**
matresses latex	*direct fuels*	*0,00*									*0,71*		
	substituted fuels	*-0,36*		*-0,59*	*-0,29*	*-0,10*							
	direct & subst. fuels incl. precomb.			-0,82	0,26	-0,20	-0,07	-0,50	-0,15				
	substituted material production												
matresses latex	**Total**			**-0,82**	**0,26**	**-0,20**	**-0,07**	**-0,50**	**-0,15**				

Table 92: Database for waste management of plastics and other materials used in the furniture sector: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
garden furniture PP	emissions from electr./steam/fuels	-302.207	-528	5
	CO2 from incinerated waste	530.150		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-68.424	-310	0
garden furniture PP	**Total**	**159.520**	**-838**	**5**
matresses PUR	emissions from electr./steam/fuels	-102.783	-224	14
	CO2 from incinerated waste	407.815		
	CH4 from landfill (wood, paper)			
	subst. production emissions	-173.766	-751	-1
matresses PUR	**Total**	**131.266**	**-975**	**12**
garden furniture Steel	emissions from electr./steam/fuels	256.470	463	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-747.270	-1.631	-22
garden furniture Steel	**Total**	**-490.800**	**-1.168**	**-18**
garden furniture Aluminium	emissions from electr./steam/fuels	98.833	184	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-873.050	-2.016	-2
garden furniture Aluminium	**Total**	**-774.218**	**-1.831**	**1**
garden furniture wood	emissions from electr./steam/fuels	-72.184	-147	6
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)		154.047	
	subst. production emissions			
garden furniture wood	**Total**	**-72.184**	**153.900**	**6**
matresses Steel	emissions from electr./steam/fuels	295.687	381	33
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions	-62.273	-136	-2
matresses Steel	**Total**	**233.414**	**245**	**31**
matresses latex	emissions from electr./steam/fuels	-79.774	-159	6
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions			
matresses latex	**Total**	**-79.774**	**-159**	**6**

Table 93: Database for waste management of plastics and other materials used in the furniture sector: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

4.7.2 Garden furniture

4.7.2.1 Mass ratios

For the calculation of mass ratios the functional unit (FU) was defined as four chairs and one table. The chairs selected have approximately the same type of construction and a height between 82 cm and 92 cm. The tables selected have a height of approximately 75 cm and a top surface of about 12.000 cm^2. Data on garden furniture were taken from the following sources:

- weighed out in different stores
- folders and written information from different companies
- web-sites.

Garden furniture: 4 chairs + 1 table (used for calculation)				
material	**total mass 4 chairs [kg]**	**total mass 1 table [kg]**	**total mass FU [kg]**	**mass ratios (plastic =1)**
plastic (PP)	8,0	6,9	14,9	1,0
steel	24,0	19,9	43,9	2,9
aluminium	40,0	12,3	52,3	3,5
wood	38,3	45,3	83,6	5,6

Table 94: Mass ratios for garden furniture used in this study

garden furniture - chairs (used for calculation)			
material	**dimension (width*depth*height) [cm]**	**total mass ca. [kg]**	**average mass per material ca. [kg]**
plastic (PP)	57*56*83	2,0	2,0
plastic (PP)	58*58*90	2,0	
steel	44*47*82	6,0	6,0
aluminium	54*60*85	12,0	10,0
aluminium	47*54*90	8,0	
wood	61*62*90	8,0	9,6
wood	62*61*92	14,0	
wood	60*58*92	12,0	
wood	67*75*87	7,0	
wood	69*76*91	8,0	
wood	62*52*89	12,0	
wood	65*70*85	6,0	

garden furniture - tables (used for calculation)						
material	**shape**	**dimension table-top (length*width*height) [cm]**	**total weight table ca. [kg]**	**table-top surface [cm2]**	**weight per table - top surface=12000cm2 (150cm*80cm) ca. [kg]**	**average weight per material ca. [kg]**
plastic (PP)	rectangular	140*100*72	8,0	14000	6,9	6,9
steel	oval	140*90 (r=45) *75	18,0	10862	19,9	19,9
aluminium	rectangular (top surface consists of braces)	120*52*76	3,2	3120	12,3	12,3
wood	rectangular	150*80*75	22,0	12000	22,0	45,3
wood	rectangular	150*90*75	34,0	13500	30,2	
wood	rectangular	150*80*76	57,0	12000	57,0	
wood	rectangular	150*70*75	70,0	10500	80,0	
wood	rectangular	145*90*76	49,0	13050	45,1	
wood	rectangular	150*90*76	42,0	13500	37,3	

garden furniture - chairs (not used for calculation)		
material	**dimension (width*depth*height) [cm]**	**total mass ca. [kg]**
plastic (PP)	61*65*109	3,5
wood	79*60*106	8,5
wood	67*75*108	8,0
wood	69*76*111	10,0
wood	65*70*106	7,0
concrete block	43*43*47	60,0
cast iron/bronze	46*48*76	15,0

garden furniture - tables (not used for calculation)			
material	**shape**	**dimension table-top (length*width*height) [cm]**	**total mass table ca. [kg]**
aluminium / glass	round	r=60 *72	18,0
concrete block	rectangular	158*80*75	287,0

Table 95: Detailed data collected for chairs and tables made of different materials.

To calculate the mass ratios finally used in this model, the mass ratios for every single material, listed in Table 94 were multiplied with the market share of the alternative materials. Market share data based on annual turnover was received from a large Austrian furniture store. These values were transformed to market data based on functional units by using data on price per kg and on kg per functional unit, leading to market shares of 55 % for steel, 23 % for aluminium and 22 % for wood. Therefore 1 kg plastic garden furniture is replaced by a mix of 1,62 kg steel, 0,81 kg aluminium and 1,23 kg wood.

4.7.3 Mattresses

4.7.3.1 Mass ratios

For the calculation of mass ratios for mattress, data on mattress cores with the same dimension was used. Data on mattress cores were received from a large Austrian mattress producer.

mattress cores (used for calculation)							
mattress core	**volume mass ca. [kg/m3]**	**mass ca. [kg]**	**dimension (length*width*height) ca. [m]**	**volume ca. [m3]**	**total mass ca. [kg]**	**average total mass ca. [kg]**	**mass ratios (plastic =1)**
PUR/foam material	35		2*0,9*0,12	0,216	7,6	8,1	1,0
PUR/cold foam	40		2*0,9*0,12	0,216	8,6		
spring		3,5	2*0,9*0,12	0,216	3,5	3,5	0,4
pin latex (natural or synthetical)	75		2*0,9*0,12	0,216	16,2	16,2	2,0

Table 96: Mass ratios for mattress cores used in this study

The market share of different materials, based on pieces, is 40 % for PUR, 20 % for steel, 35 % for latex and 5 % for other materials (data received from a large Austrian mattress producer). Therefore 1 kg PUR mattress could be replaced by a mix of 0,16 kg steel and 1,27 kg latex.

4.8 Medicine

4.8.1 Syringes and infusion containers

Medicine is another sector where the identification of possible case studies is difficult, partly due to the fact that many products made of plastics cannot be substituted by another material. In this study results are calculated for the case studies “syringes” and “infusion containers”.

4.8.1.1 Market share of plastic products

Market data is taken from an investigation carried out by Frost & Sullivan [1999] regarding the use of plastics in important application sectors within medicine in Western Europe. Analysis of the data shows that about 20 % of the total mass of plastics used for medicine is covered by syringes and 28 % is covered by blood bags and solution bags. The total mass of plastics used for medicine (without packaging) is given with 128 kt/a. From the perspective of the total market of plastic products, this number is 648 kt/a (see chapter 2.1). If the second figure is used as a basis for comparison, the shares of syringes and infusion bags would be 4 % and 5,6 % respectively.

It is a frequent finding that bottom-up data underestimates the real value, and top-down data overestimates it. For this study, the share of syringes is assumed to be 8 % and the share of infusion bags is assumed to be 11 % of the total mass of plastics used for medicine, which is assumed to be 648 kt/a. The remaining 81 % of the total mass of medical applications are assumed to be not substitutable (50 %) or are not covered by the case studies of this report (31 %).

4.8.1.2 Mass ratios

Two 5 ml - syringes were compared: a PP syringe (mass: 3,97 grams) for single-use and a glass syringe (mass: 23,1 grams) for reuse. The glass syringe can be re-used after proper cleaning and sterilizing (see below). For this study, we assumed the syringe to be re-used 50 times before being disposed of. The resulting mass ratio for the glass syringe is therefore (23,1/50) / 3,97 = 0,12.

Further on, two 500 ml infusion containers for a 0,9% NaCl (isotonic brine) were compared: a PVC infusion bag and a glass infusion bottle. The containers were opened, emptied of their contents, dried and weighed. PVC bag mass: 23 g, glass bottle mass: 226 g. The resulting mass ratio for the glass syringe is therefore 226 / 23 = 9,83.

4.8.1.3 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- Data for PP and PVC (energy for processing included) are taken from the inventories published by PlasticsEurope.
- White glass: ETH & EMPA [1996].

Material	Product	Total energy demand MJ/kg	coal MJ/kg	oil MJ/kg	gas MJ/kg	hydro MJ/kg	nuclear MJ/kg	lignite MJ/kg	wood / biomass MJ/kg	other MJ/kg
PP	injection moulding	**118,84**	12,58	45,74	48,79	0,81	9,82	0,07	0,86	0,19
PVC	UPVC film	**66,25**	6,35	19,32	29,83	0,87	7,85	0,69	0,21	1,13
Glass	white	**12,74**	0,93	8,34	0,57	0,59	2,18	0,12	0,00	0,00

Material	Product	CO_2 mg/kg	CH_4 mg/kg	N_2O mg/kg
PP	injection moulding	4.013.497	19.990	0,1
PVC	UPVC film	2.256.381	10.118	0,2
Glass	white	748.000	781	2,0

Table 97: Energy demand and emissions of the production phase of medical products used in this calculation model.

4.8.1.4 Energy and emissions of use phase

The glass syringe has to be sterilised before reuse. To quantify this effect within the use-phase, it is assumed that 100 syringes are sterilised together in a machine consuming 1,13 kWh electricity for the heating process (h&p VARIOKLAV 300 E steam sterilizer: heating capacity = 3,4 kW, heating-up time = 20 min). 100 glass syringes substitute 0,4 kg plastics, therefore 10,3 MJ_{el} are saved per kg plastics when using plastic syringes instead of glass syringes.

4.8.1.5 Energy and emissions of waste phase

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The tables below show the resulting database per kg of plastics in the sector of furniture.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ
syringes PP	*direct fuels*	*0,01*									*0,78*		
	substituted fuels	*-1,18*		*-1,85*	*-0,93*	*-0,31*							
	direct & subst. fuels incl. precomb.			-2,62	-0,82	-0,65	-0,23	-1,66	-0,51				
	substituted material production												
syringes PP	**Total**			**-2,62**	**-0,82**	**-0,65**	**-0,23**	**-1,66**	**-0,51**				
infusion containers PVC	*direct fuels*	*0,00*									*0,78*		
	substituted fuels	*-0,73*		*-1,14*	*-0,57*	*-0,19*							
	direct & subst. fuels incl. precomb.			-1,61	-0,17	-0,40	-0,14	-1,02	-0,31				
	substituted material production												
infusion containers PVC	**Total**			**-1,61**	**-0,17**	**-0,40**	**-0,14**	**-1,02**	**-0,31**				
syringes Glass	*direct fuels*										*0,10*		
	substituted fuels												
	direct & subst. fuels incl. precomb.			0,00	0,12	0,00	0,00	0,00	0,00				
	substituted material production												
syringes Glass	**Total**			**0,00**	**0,12**	**0,00**	**0,00**	**0,00**	**0,00**				

Table 98: Database for waste management of plastics and other materials used in the medicine sector: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
syringes PP	emissions from electr./steam/fuels	-376.530	-660	5
	CO2 from incinerated waste	628.571		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
syringes PP	**Total**	**252.041**	**-660**	**5**
infusion containers PVC	emissions from electr./steam/fuels	-207.209	-376	6
	CO2 from incinerated waste	282.051		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
infusion containers PVC	**Total**	**74.842**	**-376**	**6**
syringes Glass	emissions from electr./steam/fuels	8.489	11	1
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions			
syringes Glass	**Total**	**8.489**	**11**	**1**

Table 99: Database for waste management of plastics and other materials used in the medicine sector: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

4.9 Footwear

4.9.1 Soles

4.9.1.1 Market share of plastic products and alternative materials

The total mass of plastics used for shoes is taken from Waste Watch & Recoup [2003]. Private investigations have shown that usually the mass of the sole covers about 2/3 of the mass of a total shoe. Based on this rough value it is assumed in this study that about 2/3 of plastics used in the footwear sector are used for soles. Additionally it is assumed in this study that the mass ratios used for the substitution model are representative for about 2/3 of the total market of plastic soles.

Naturally the lack of data and the rough assumptions described above result in high values for the assumed uncertainties (see Table 110 and Table 111).

Data on the market shares of different materials used for soles are taken from Bayer [2004]: PVC 23 %, PUR 7 %, rubber 54 % (general rubber 26 % and thermoplastic rubber 28 %), leather 9 % and other materials 7 %.

4.9.1.2 Mass ratios

Data on masses of soles made of different materials were received from a big producer. The data is referring to comparable soles of the UK shoe size "6": PVC 242 g, PUR 217 g, thermoplastic rubber 237 g and leather 236 g.

A lower lifetime is assumed for leather soles (factor 0,7) and for rubber (factor 0,9) compared to plastic soles.

The combination of these masses and lifetime factors with the market shares given above leads to the mass ratios listed in the following table.

Table of mass ratios	**Market share plastics**	PVC	PUR	**Altern. mat. - Total**	Leather	Rubber
soles	0,50%	0,77	0,23	1,16	0,20	0,96

Table 100: Mass ratios for shoe soles used in this study

4.9.1.3 Energy and emissions of production phase

Data on energy demand and emissions of the production phase are taken form the following studies:

- Data for PVC and PUR (energy for processing included) are taken from the inventories published by PlasticsEurope.
- Leather: Mila [1998]
- Rubber: [Ecoinvent 2004].

Material	**Product**	**Total energy demand** **MJ/kg**	coal MJ/kg	oil MJ/kg	gas MJ/kg	hydro MJ/kg	nuclear MJ/kg	lignite MJ/kg	wood / biomass MJ/kg	other MJ/kg
PVC	injection moulding	**93,38**	5,90	30,21	28,66	1,80	20,17	0,77	4,67	1,19
PUR	rigid foam	**104,61**	11,32	31,66	49,55	0,68	7,50	2,30	0,42	1,17
Leather	shoes	**2,64**	0,82	0,82	0,82	0,19	0,00	0,00	0,00	0,00
Rubber	at plant	**100,60**	5,49	62,93	24,18	2,34	0,00	4,43	0,89	0,34

Material	**Product**	CO_2 mg/kg	CH_4 mg/kg	N_2O mg/kg
PVC	injection moulding	2.006.060	10.137	0,2
PUR	rigid foam	3.924.185	19.618	18,0
Leather	shoes	174.393	3.441	1.150,6
Rubber	at plant	3.035.400	13.431	140,3

Table 101: Energy demand and emissions of the production phase of shoe soles used in this calculation model.

4.9.1.4 Energy and emissions of waste phase

For a general description of the model and data used to calculate the energy and emissions within waste management see chapter 3.4. The tables below show the resulting database per kg of plastics in the sector of furniture.

		electricity	steam	coal	oil	gas	hydro	nuclear	lignite	wood / biomass	petrol/diesel	fuel oil extra light	other
		MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ	MJ
soles PVC	*direct fuels*	*0,00*									*0,44*		
	substituted fuels	*-0,73*		*-1,14*	*-0,57*	*-0,19*							
	direct & subst. fuels incl. precomb.			-1,61	-0,55	-0,40	-0,14	-1,02	-0,32				
	substituted material production												
soles PVC	**Total**			**-1,61**	**-0,55**	**-0,40**	**-0,14**	**-1,02**	**-0,32**				
soles PUR	*direct fuels*	*0,00*									*0,44*		
	substituted fuels	*-0,70*		*-1,09*	*-0,55*	*-0,18*							
	direct & subst. fuels incl. precomb.			-1,54	-0,51	-0,38	-0,14	-0,98	-0,30				
	substituted material production												
soles PUR	**Total**			**-1,54**	**-0,51**	**-0,38**	**-0,14**	**-0,98**	**-0,30**				
soles leather	*direct fuels*	*0,00*									*0,44*		
	substituted fuels	*-0,49*		*-0,77*	*-0,39*	*-0,13*							
	direct & subst. fuels incl. precomb.			-1,09	-0,22	-0,27	-0,10	-0,69	-0,21				
	substituted material production												
soles leather	**Total**			**-1,09**	**-0,22**	**-0,27**	**-0,10**	**-0,69**	**-0,21**				
soles rubber	*direct fuels*	*0,00*									*0,44*		
	substituted fuels	*-0,43*		*-0,67*	*-0,34*	*-0,11*							
	direct & subst. fuels incl. precomb.			-0,95	-0,13	-0,23	-0,08	-0,60	-0,19				
	substituted material production												
soles rubber	**Total**			**-0,95**	**-0,13**	**-0,23**	**-0,08**	**-0,60**	**-0,19**				

Table 102: Database for waste management of plastics and other materials used for shoe soles: Aggregated energy demand of waste processes and saved energy consumption due to recycling and energy recovery per kg material, base case.

		CO2	CH4	N2O
		mg	mg	mg
soles PVC	emissions from electr./steam/fuels	-234.933	-410	3
	CO2 from incinerated waste	282.051		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
soles PVC	**Total**	**47.118**	**-410**	**3**
soles PUR	emissions from electr./steam/fuels	-223.748	-392	3
	CO2 from incinerated waste	476.667		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
soles PUR	**Total**	**252.919**	**-392**	**3**
soles leather	emissions from electr./steam/fuels	-147.463	-263	3
	CO2 from incinerated waste			
	CH4 from landfill (wood, paper)			
	subst. production emissions			
soles leather	**Total**	**-147.463**	**-263**	**3**
soles rubber	emissions from electr./steam/fuels	-124.029	-224	3
	CO2 from incinerated waste	403.333		
	CH4 from landfill (wood, paper)			
	subst. production emissions			
soles rubber	**Total**	**279.305**	**-224**	**3**

Table 103: Database for waste management of plastics and other materials used for shoe soles: Aggregated GHG emissions of waste processes and saved GHG emissions due to recycling and energy recovery per kg material, base case.

5 RESULTS

In chapter 4 all energy and emission data (per kg material) for production, use and waste management for all case studies and all materials investigated were described. Additionally the mass ratios needed to compare the products with regards to a functional unit were calculated. Combination of data per kg material with the mass ratios finally allows the comparison between the energy demand and the GHG emissions of plastic products and alternative products (calculation process see chapter 3.2).

The respective results generated for each case study are presented in Chapter 5.1. The results for the energy and GHG emissions saved by plastic products are given in MJ / kg plastic product and g CO_2-equivalent per kg plastic product respectively.

Finally the results of the case studies analysed are aggregated with regard to the market shares of plastic products on the total plastics market in Western Europe. These results are presented in chapter 5.2 and are given in Mill GJ/a and 1.000 t (= “kt”) CO_2-equivalent per year respectively.

Example “buckets” (to follow the calculation, see also Annex I, case study “buckets”):

Saved energy per kg plastic product =
= energy per kg alternative product x mass ratio – energy per kg plastic product
= (38,4 MJ/kg (production, Table 83) – 1,4 MJ/kg (waste phase, Table 85, sum of values for keep fresh boxes steel, which are also used for steel buckets)) x 3,56 (mass ratio, Table 87) – (118,8 MJ/kg (production, Table 83) – 8,8 MJ/kg (waste phase, Table 84))
= **21,7 MJ/kg**

Saved energy per year in Western Europe =
= saved energy per kg plastic product x (total plastics market x share housewares x share of buckets in housewares)
= 21,7 MJ/kg x (38.123 kt (see chapter 5.2) x 5 % (see chapter 2.1) x 10 % (see chapter 4.6.1.1)) / 1.000
= **4,1 Mill GJ/a**

5.1 Results on the level of case studies

The detailed results on the level of case studies are presented in Annex I. The difference regarding energy demand and GHG emissions per kg plastic product is presented in the table below for all case studies analysed. The results are split into the life-cycle phases production, use and waste management. Additionally, the total energy figures are also split into shares of renewable fuels (wood and other biogenic fuels, hydropower to produce electricity) and non-renewable fuels (coal, oil, gas, lignite, uranium). CO_2 emissions form combustion of renewable fuels (wood, etc.) are not included in the calculated GHG emissions, which is a commonly accepted procedure.

Results of case studies analysed	Energy savings in each case study per kg plastics					
	MJ/kg pl. Total	MJ/kg pl. Production	MJ/kg pl. Use	MJ/kg pl. Waste M.	MJ/kg pl. Non-Renew.	MJ/kg pl. Renewable
small packaging	35,5	14,0	3,4	18,1	-6,2	41,6
beverage bottles	76,5	37,1	11,6	27,9	69,0	7,5
other bottles	19,9	-9,3	3,4	25,8	16,1	3,8
other rigid packaging	-10,8	-32,3	3,4	18,1	-35,2	24,4
shrink and stretch films	98,9	63,8	0,0	35,0	48,6	50,3
carrier bags	34,8	26,5	0,0	8,3	-19,3	54,1
other flexible packaging	14,4	2,3	3,4	8,7	-22,7	37,1
big drain and sewer pipes	-3,6	-3,6	0,0	0,0	-4,0	0,4
small drain and sewer p.	27,8	25,9	0,0	1,9	24,1	3,7
big drinking water pipes	6,6	6,6	0,0	0,0	2,0	4,6
small drinking water pipes	71,0	73,6	0,0	-2,6	59,6	11,4
agricultural pipes	27,8	25,9	0,0	1,9	24,1	3,7
conduit pipes	77,5	73,8	0,0	3,8	70,4	7,1
gas pipes	153,9	139,4	0,0	14,5	142,8	11,1
heating and plumbing p.	-0,2	-1,7	0,0	1,5	-5,8	5,6
industry pipes	64,7	71,0	0,0	-6,3	48,0	16,6
insulation	-0,2	-4,8	0,0	4,6	-2,8	2,6
flooring	-31,6	-40,0	0,0	8,4	-74,7	43,1
windows	77,3	-2,9	80,5	-0,2	53,5	23,8
housing	68,2	67,5	0,0	0,7	33,9	34,3
insulation in refrig.	1.778,7	-68,3	1.841,4	5,6	1.664,3	114,4
under the hood	83,7	-11,5	109,2	-14,0	69,1	14,5
exterior and cockpit	96,5	-28,3	130,5	-5,7	84,5	12,0
other automotive parts	86,1	17,7	81,5	-13,2	81,1	5,0
keep fresh boxes	8,0	-2,4	0,0	10,4	-6,5	14,4
buckets	21,7	17,9	0,0	3,8	12,1	9,6
waste bins	15,8	-1,8	0,0	17,7	11,7	4,1
garden furniture	115,9	136,6	0,0	-20,7	53,7	62,2
matresses	17,3	12,3	0,0	5,0	19,5	-2,2
syringes	-76,6	-116,9	33,8	6,5	-77,1	0,5
infusion containers	100,8	96,0	0,0	4,8	102,3	-1,5
soles	2,1	0,7	0,0	1,4	5,0	-2,9

Results of case studies analysed	Energy savings in each case study per kg plastics					
	MJ/kg pl. Total	MJ/kg pl. Production	MJ/kg pl. Use	MJ/kg pl. Waste M.	MJ/kg pl. Non-Renew.	MJ/kg pl. Renewable
Packaging	30,6	5,5	3,8	21,4	3,4	27,2
Building - Pipes	33,1	31,9	0,0	1,2	28,0	5,0
Building - Non Pipes	17,8	-10,3	24,3	3,8	1,8	16,0
Electric/electronic	274,2	51,2	221,8	1,3	230,3	44,0
Automotive	88,1	-9,5	108,9	-11,3	76,6	11,5
Housewares	12,3	1,8	0,0	10,5	0,9	11,4
Furniture	86,3	99,3	0,0	-13,0	43,4	42,9
Medicine	-1,9	-27,3	19,6	5,8	-1,6	-0,3
Footwear	2,1	0,7	0,0	1,4	5,0	-2,9
Total	37,8	9,5	15,3	13,1	15,5	22,4

Table 104: Difference in energy demand of a plastic product compared to alternative products (mix of possible substitutes) within the total life cycle. Positive figures represent an energy saving realised by plastic products (less energy consumed by plastic product than by alternative products). In the first part of the table figures are presented for all case studies analysed. In the second part of the table the results are aggregated for the most important application sectors.

Results of case studies analysed	GHG emission savings			
	g/kg pl. Total	g/kg pl. Production	g/kg pl. Use	g/kg pl. Waste M.
small packaging	3.129	1.104	249	1.775
beverage bottles	5.033	3.287	875	870
other bottles	3.083	2.708	249	125
other rigid packaging	480	-737	249	968
shrink and stretch films	7.446	4.092	0	3.354
carrier bags	2.425	294	0	2.131
other flexible packaging	1.793	286	249	1.258
big drain and sewer pipes	1.642	1.642	0	0
small drain and sewer p.	3.462	3.628	0	-166
big drinking water pipes	3.228	3.228	0	0
small drinking water pipes	7.089	7.634	0	-546
agricultural pipes	3.462	3.628	0	-166
conduit pipes	7.404	7.411	0	-7
gas pipes	12.316	12.548	0	-232
heating and plumbing p.	2.423	3.055	0	-632
industry pipes	5.596	6.518	0	-922
insulation	923	883	0	40
flooring	2.196	-2.298	0	4.494
windows	6.598	-207	5.102	1.704
housing	4.127	3.160	0	967
insulation in refrig.	79.047	-2.585	81.659	-27
under the hood	7.508	505	8.277	-1.274
exterior and cockpit	9.027	-16	9.889	-846
other automotive parts	5.854	308	6.178	-632
keep fresh boxes	1.796	1.596	0	199
buckets	3.541	4.105	0	-563
waste bins	2.121	3.040	0	-920
garden furniture	9.430	6.815	0	2.615
matresses	-951	-774	0	-177
syringes	-3.092	-4.353	1.498	-237
infusion containers	7.663	7.642	0	21
soles	763	618	0	145

Results of case studies analysed	GHG emission savings			
	g/kg pl. Total	g/kg pl. Production	g/kg pl. Use	g/kg pl. Waste M.
Packaging	2.998	1.386	279	1.332
Building - Pipes	4.174	4.361	0	-187
Building - Non Pipes	2.856	5	1.541	1.311
Electric/electronic	13.151	2.468	9.835	847
Automotive	7.563	301	8.252	-990
Housewares	2.210	2.387	0	-177
Furniture	6.315	4.538	0	1.777
Medicine	1.436	697	867	-129
Footwear	763	618	0	145
Total	3.602	1.660	979	962

Table 105: Difference in GHG emissions of a plastic product compared to alternative products (mix of possible substitutes) within the total life cycle. Positive figures represent an energy saving realised by plastic products (less energy consumed by plastic product than by alternative products). In the first part of the table figures are presented for all case studies analysed. In the second part of the table the results are aggregated for the most important application sectors.

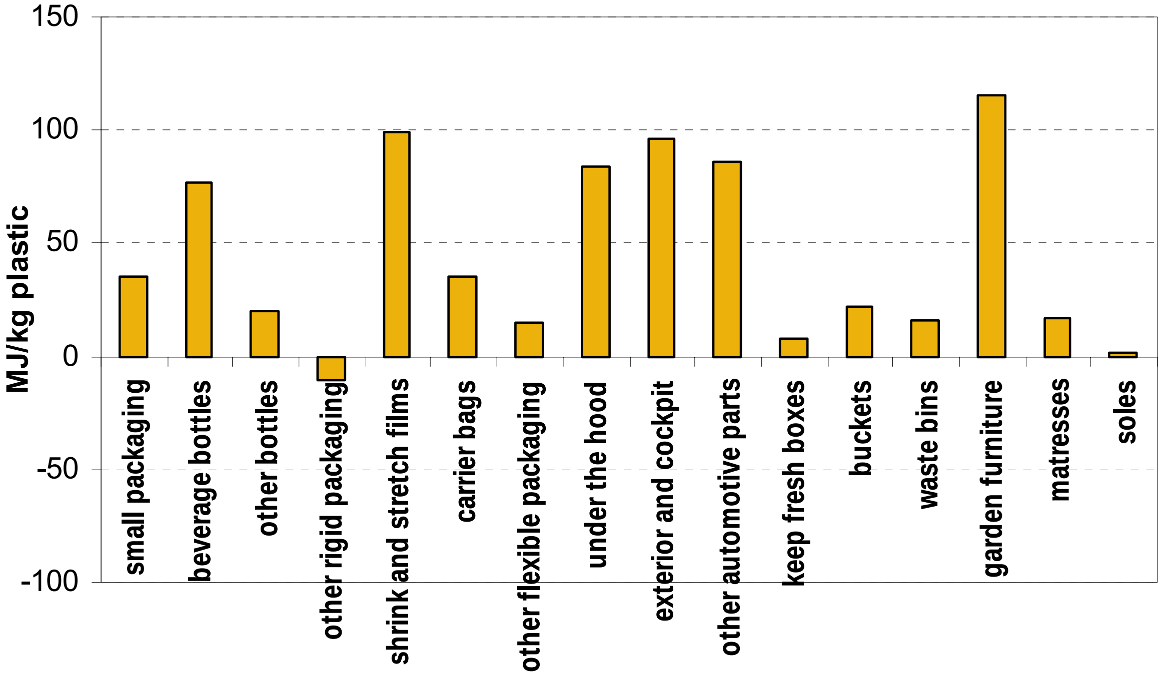

Figure 4: *Energy savings of plastic products compared to alternative materials, given in MJ per kg plastic product. Figure shows first part of case studies.*

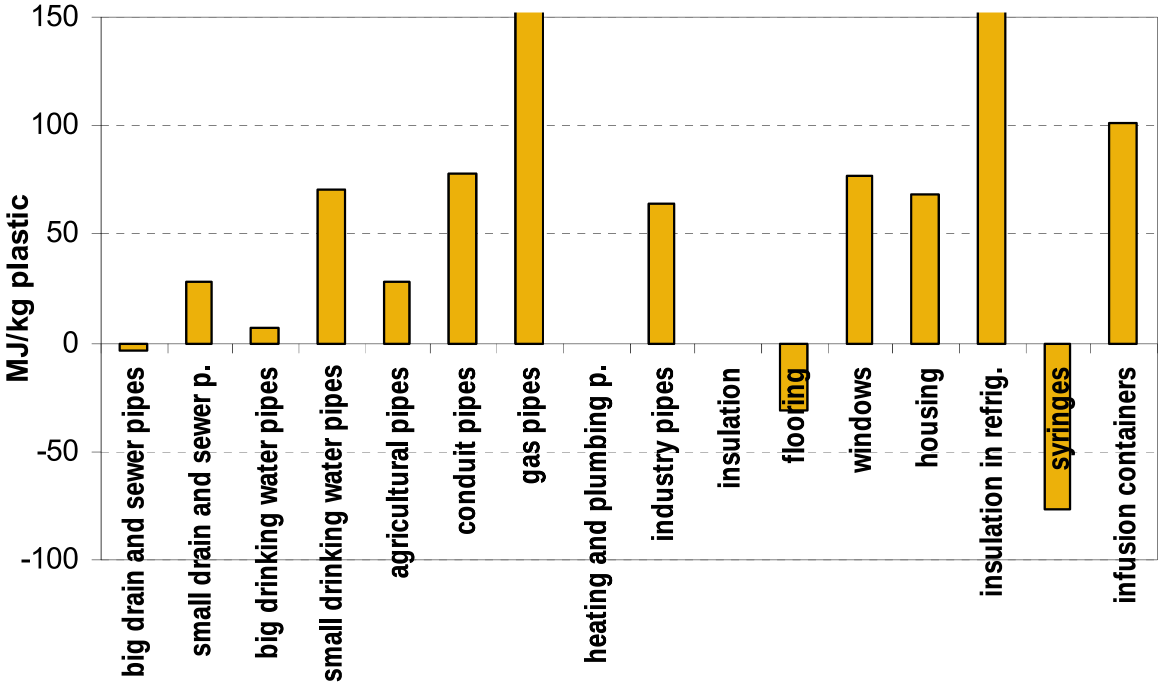

Figure 5: *Energy savings of plastic products compared to alternative materials, given in MJ per kg plastic product. Figure shows second part of case studies. The value for “gas pipes” is 154 MJ/kg PE, the value for “insulation in refrigerators” is approx. 1.800 MJ/kg PUR.*

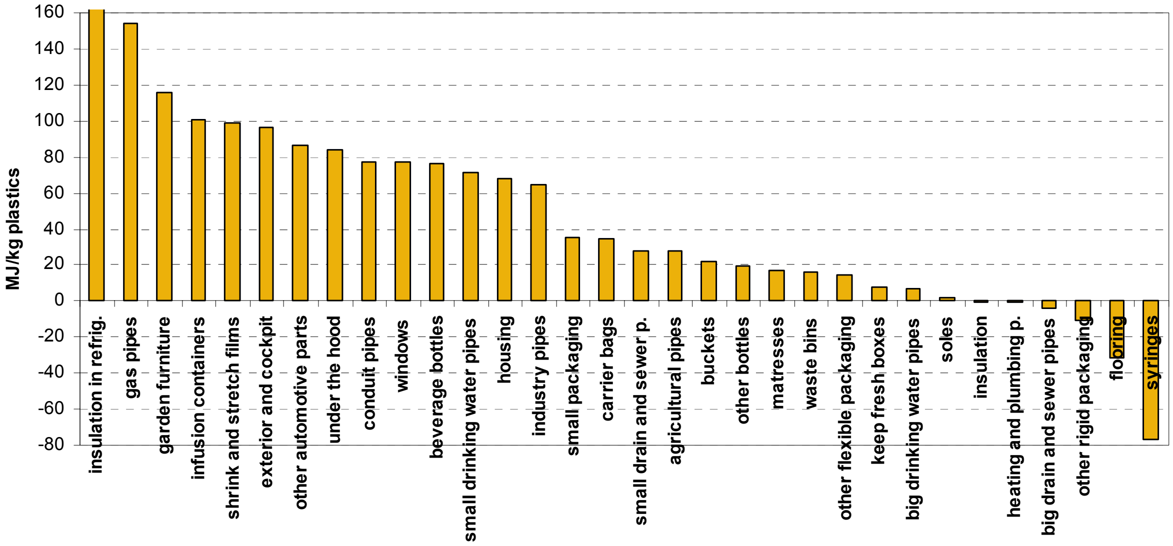

Figure 6: Energy savings of plastic products compared to alternative materials. Results in descending sorting. The value for “insulation in refrigerators” is approx. 1.800 MJ/kg PUR.

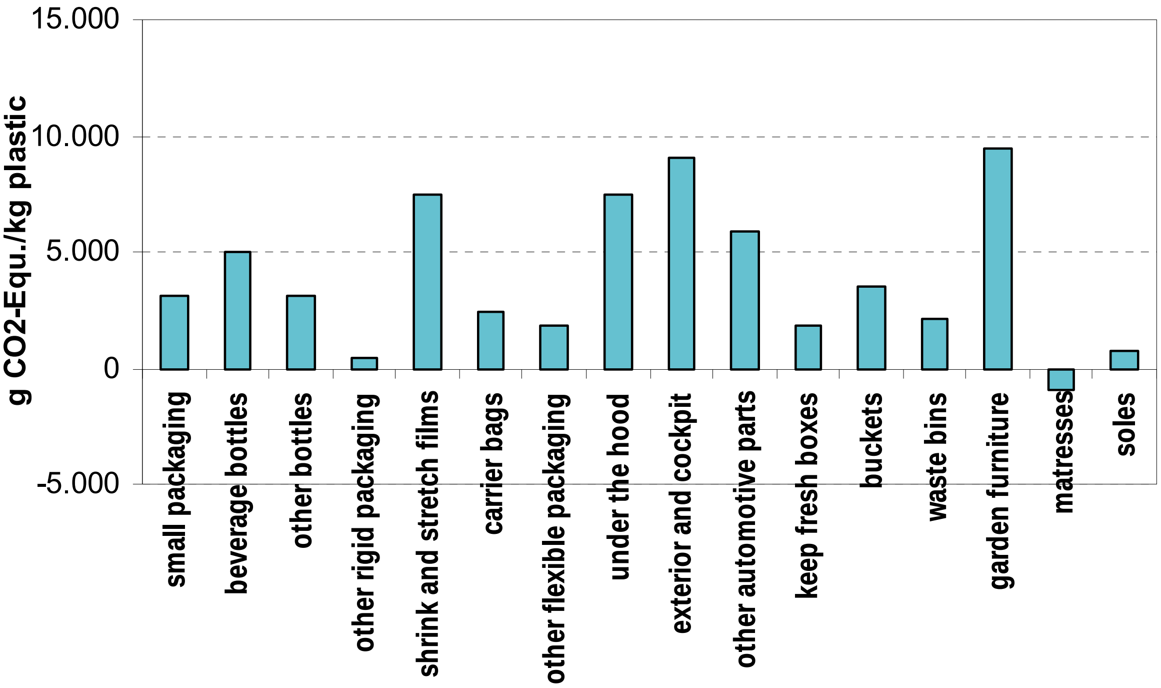

Figure 7: GHG emission savings of plastic products compared to alternative materials, given in gram (g) CO_2-equivalent per kg plastic product. Figure shows first part of case studies.

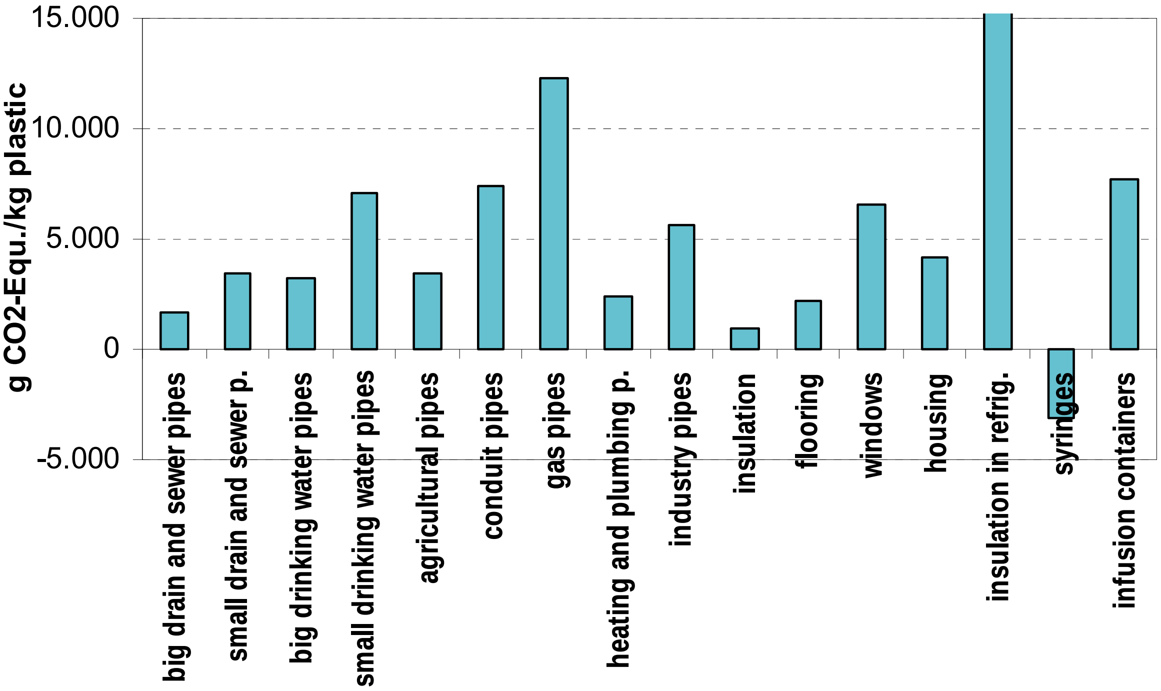

Figure 8: GHG emission savings of plastic products compared to alternative materials, given in gram (g) CO_2-equivalent per kg plastic product. Figure shows second part of case studies. The value for “insulation in refrigerators” is approx. 79.000 g/kg PUR.

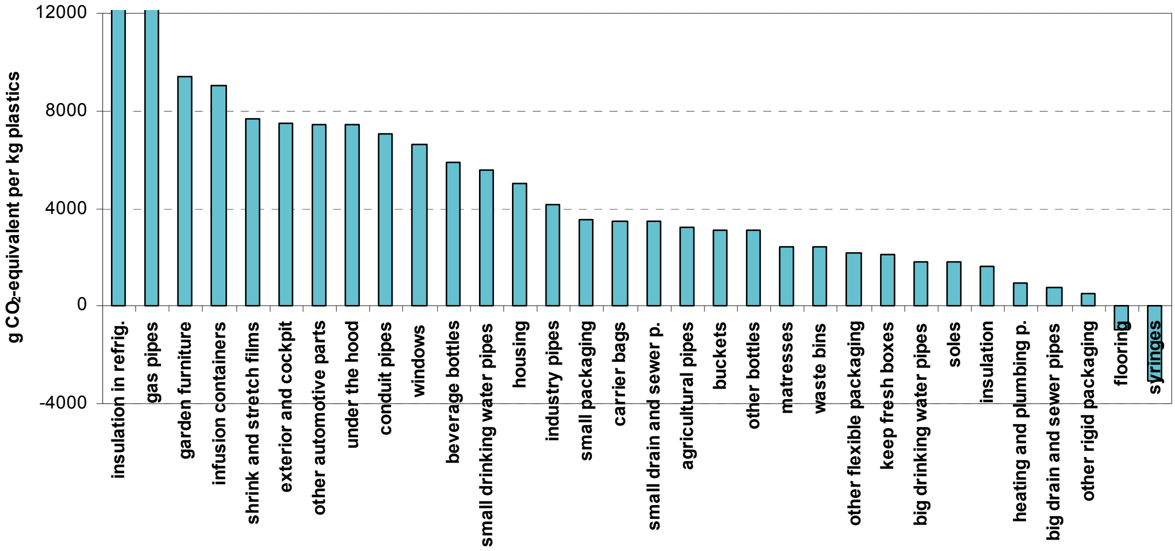

Figure 9: GHG emission savings of plastic products compared to alternative materials. Results in descending sorting. The value for “gas pipes” is 12.300 g/kg PE, the value for “insulation in refrigerators” is approx. 79.000 g/kg PUR.

Most results are within a range of 0 – 100 MJ/kg plastics and 0 – 8.000 g CO2-equivalent per kg plastics. Outstanding results are:

- Insulation in refrigerators and freezers: The enormous energy saving of about 1.800 MJ per kg plastic material is caused by the lower consumption of electricity in the use phase. The energy saved within one year is already higher then the energy necessary to produce the PUR foam for insulation. Additionally a lifetime of 10 years is assumed; therefore the annual effect per kg plastics is multiplied by 10 within the total lifetime of the product.
- Gas pipes, garden furniture, shrink and stretch films and infusion container: In these case studies a high mass ratio is combined with a mix of (relatively) energy-intensive materials for substitution.
- The energy demands for big drain and sewer pipes, heating and plumbing pipes, insulation materials and soles are not significantly different from the energy demands of the alternative materials, as the difference is smaller than 5 % of the total life-cycle energy of the plastic product. Different assumptions regarding mass ratios, lifetime and production energy can change the result to a small positive or negative value.
- Despite of the high mass ratio, the result for big drain and sewer pipes is slightly negative, because a high proportion of the plastic pipes is substituted by concrete pipes in the calculation model, which don’t need much energy to be produced.
- The slightly negative result for “other rigid packaging” is a result of higher thickness of these plastic packaging applications, leading to a smaller mass ratio than for other packaging sectors.
- The only results with a significant negative result are syringes and flooring. The case study on syringes is based on the assumption, that the glass syringe is reused 50 times, which results in a very low mass ratio. For flooring, a mass ratio of 0,91 is combined with less energy needed to produce 1kg of Linoleum flooring than 1 kg of PVC flooring.

Generally, the relation of results for energy effects and for GHG effects can differ due to following reasons:

- Different share of biogenic fuels, which are included in energy consumption, but are not included in the calculation of GHG emissions, which is a commonly accepted procedure.
- Different relative shares of coal, fuel oil and gas, which cause different amounts of GHG emissions in the combustion and precombustion phase per MJ fuel used
- GHG emissions are not only produced by combustion processes, but also by other effects. Examples are CH_4 emissions in the precombustion phase of coal and gas, CH_4 coming from agricultural processes (food production, leather production), and in this study especially CH_4 emissions from landfills (coming from the degradation of wood, paper, etc.); CO_2 emissions from the consumption of carbon electrodes in aluminium production; CO_2 emissions from heating of certain minerals in the glass production, etc.

For further discussion of results, see next chapter.

5.2 Results of case studies analysed on the level of the Western European market

The detailed results of the case studies analysed on the level of the Western European market are presented in Annex II. These results are calculated by multiplication of the results of the case studies per kg plastics (see Annex I) with the market share of plastic products (in tonnes) represented by each case study. The total consumption of plastic products in Western Europe in 2002 was 38.123 kt. The relative market shares of application sectors are shown in the second column of the table below.

The calculations show that the total life-cycle energy demand of the plastic products analysed is 2.380 Mill GJ/a, whereas the alternative products, needed for a theoretical substitution, would consume 3.260 Mill GJ/a in their total life cycle. Therefore the plastic products analysed need 880 Mill GJ less energy per year than their potential substitutes.

Results of	**market**	**Energy production**		**Energy use phase**		**Energy waste**		**Energy total life-cycle**	
case studies	**share of**	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a
analysed	**case study**	Plastics	Alternat. materials	Plastics	Alternat. materials	Plastics	Alternat. materials	Plastics	Alternat. materials
small packaging	2,45%	93	106	-48	-44	-13	4	32	65
beverage bottles	4,57%	147	211	24	44	-48	0	122	255
other bottles	5,95%	233	212	-116	-108	-53	6	65	110
other rigid packaging	11,18%	442	304	-217	-203	-102	-25	123	77
shrink and stretch films	5,85%	205	347	0	0	-108	-30	97	318
carrier bags	1,13%	40	51	0	0	-10	-7	29	44
other flexible packaging	6,13%	206	211	-119	-111	-45	-25	42	76
big drain and sewer pipes	1,69%	52	50	0	0	0	0	52	50
small drain and sewer p.	1,69%	52	69	0	0	-3	-2	49	67
big drinking water pipes	0,73%	23	25	0	0	0	0	23	25
small drinking water pipes	0,73%	23	44	0	0	-1	-2	22	41
agricultural pipes	0,62%	19	25	0	0	-1	-1	18	25
conduit pipes	0,55%	16	32	0	0	-1	0	16	32
gas pipes	0,35%	12	31	0	0	-3	-1	9	30
heating and plumbing p.	0,28%	10	9	0	0	-1	-1	9	9
industry pipes	0,28%	9	17	0	0	-1	-2	9	15
insulation	3,76%	139	132	0	0	-3	4	137	136
flooring	1,23%	65	46	0	0	-6	-2	59	44
windows	2,16%	71	69	499	565	-11	-12	559	623
housing	1,05%	49	76	0	0	-4	-4	44	72
insulation in refrig.	0,14%	6	2	251	352	-0	0	256	354
under the hood	1,45%	65	59	126	186	-3	-11	188	235
exterior and cockpit	0,96%	45	35	83	131	-4	-6	124	159
other automotive parts	0,77%	28	33	67	91	-0	-4	95	120
keep fresh boxes	1,50%	68	67	0	0	-5	1	63	67
buckets	0,50%	23	26	0	0	-2	-1	21	25
waste bins	0,50%	17	16	0	0	-7	-4	10	13
garden furniture	1,40%	63	136	0	0	-4	-15	59	121
matresses	0,60%	24	27	0	0	-1	-0	22	26
syringes	0,19%	8	0	0	2	-0	0	8	3
infusion containers	0,14%	3	8	0	0	-0	0	3	8
soles	0,50%	18	18	0	0	-1	-0	18	18
Totals		**2.276**	**2.496**	**550**	**906**	**-443**	**-138**	**2.383**	**3.264**

Table 106: Energy consumption of plastic products and their potential substitutes in their total life cycle, split into life cycle phases production, use and waste management. Positive signs stand for energy consumption, negative signs indicate energy credits for saved food losses, saved primary production (by recycling) and saved production of electricity and heat (by energy recovery).

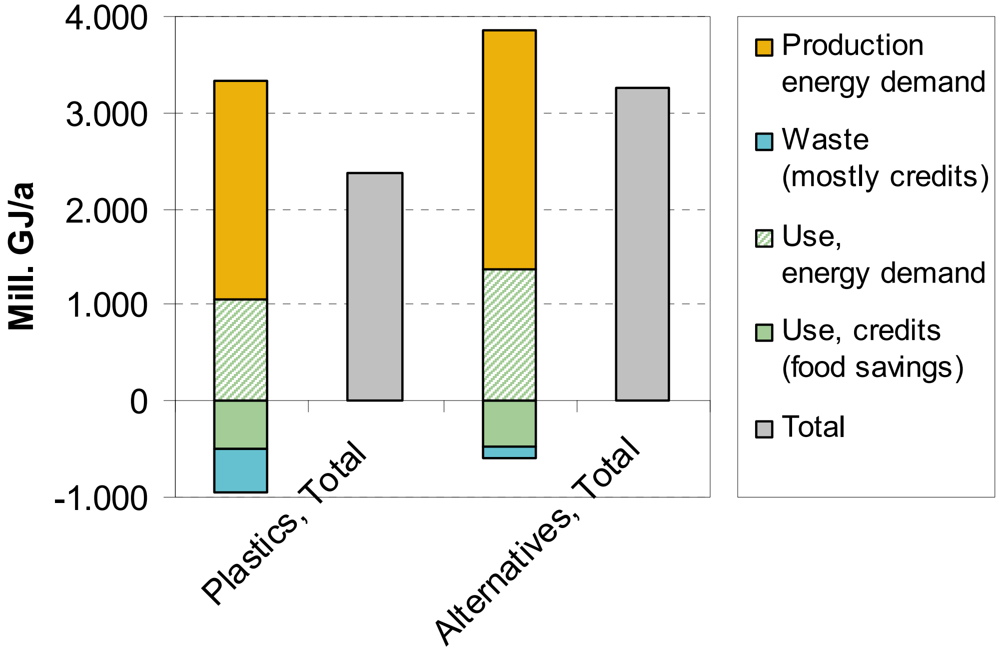

Figure 10: Energy consumption of plastic products and their potential substitutes in their total life cycle, split into life cycle phases production, use and waste management. Positive values stand for energy consumption, negative values indicate energy credits for saved food losses, saved primary production (by recycling) and saved production of electricity and heat (by energy recovery).

The tables below present the difference regarding energy demand and GHG emissions for all case studies analysed (partly aggregated to main application sectors) in Mill GJ/a and kt CO_2-equivalent per year in Western Europe. The results are split into the life-cycle phases production, use and waste management. Additionally, the energy savings are also split into shares of renewable fuels (wood and other biogenic fuels, hydropower to produce electricity) and non-renewable fuels (coal, oil, gas, lignite, uranium). CO_2 emissions form combustion of renewable fuels (wood, etc.) are not included in the calculated GHG emissions.

Results of case studies analysed	**Energy savings per year in Western Europe**					
	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a
	Total	Production	Use	Waste M.	Non-Renew.	Renewable
small packaging	33,1	13,0	3,2	16,9	-5,7	38,9
beverage bottles	133,3	64,6	20,1	48,6	120,3	13,1
other bottles	45,1	-21,2	7,7	58,6	36,6	8,6
other rigid packaging	-46,0	-137,6	14,5	77,1	-150,2	104,2
shrink and stretch films	220,7	142,5	0,0	78,2	108,4	112,3
carrier bags	15,0	11,4	0,0	3,6	-8,3	23,3
other flexible packaging	33,7	5,4	7,9	20,4	-53,0	86,7
big drain and sewer pipes	-2,3	-2,3	0,0	0,0	-2,6	0,3
small drain and sewer p.	18,0	16,7	0,0	1,2	15,5	2,4
big drinking water pipes	1,8	1,8	0,0	0,0	0,6	1,3
small drinking water pipes	19,6	20,4	0,0	-0,7	16,5	3,1
agricultural pipes	6,6	6,1	0,0	0,5	5,7	0,9
conduit pipes	16,4	15,6	0,0	0,8	14,9	1,5
gas pipes	20,3	18,4	0,0	1,9	18,8	1,5
heating and plumbing p.	0,0	-0,2	0,0	0,2	-0,6	0,6
industry pipes	6,8	7,5	0,0	-0,7	5,1	1,8
insulation	-0,3	-6,9	0,0	6,6	-4,0	3,7
flooring	-14,9	-18,8	0,0	3,9	-35,2	20,3
windows	63,6	-2,4	66,2	-0,2	44,0	19,6
housing	27,4	27,1	0,0	0,3	13,6	13,8
insulation in refrig.	97,8	-3,8	101,3	0,3	91,5	6,3
under the hood	46,3	-6,4	60,5	-7,8	38,3	8,0
exterior and cockpit	35,2	-10,3	47,6	-2,1	30,8	4,4
other automotive parts	25,4	5,2	24,0	-3,9	23,9	1,5
keep fresh boxes	4,5	-1,4	0,0	5,9	-3,7	8,3
buckets	4,1	3,4	0,0	0,7	2,3	1,8
waste bins	3,0	-0,4	0,0	3,4	2,2	0,8
garden furniture	61,9	72,9	0,0	-11,1	28,6	33,2
matresses	4,0	2,8	0,0	1,1	4,5	-0,5
syringes	-5,5	-8,3	2,4	0,5	-5,5	0,0
infusion containers	5,2	5,0	0,0	0,3	5,3	-0,1
soles	0,4	0,1	0,0	0,3	0,9	-0,6

Results of case studies analysed	**Energy savings per year in Western Europe**					
	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a	Mill GJ/a
	Total	Production	Use	Waste M.	Non-Renew.	Renewable
Packaging	435,0	78,1	53,4	303,4	48,0	387,0
Building - Pipes	87,2	84,0	0,0	3,1	73,9	13,3
Building - Non Pipes	48,5	-28,1	66,2	10,4	4,9	43,6
Electric/electronic	125,2	23,4	101,3	0,6	105,1	20,1
Automotive	106,9	-11,5	132,1	-13,7	93,0	13,9
Housewares	11,7	1,7	0,0	10,0	0,8	10,9
Furniture	65,8	75,7	0,0	-9,9	33,1	32,7
Medicine	-0,2	-3,4	2,4	0,7	-0,2	0,0
Footwear	0,4	0,1	0,0	0,3	0,9	-0,6
Total	880,4	220,0	355,4	304,9	359,6	520,8

Table 107: Difference in energy demand of plastic products compared to alternative materials (mix of possible substitutes) within the total life cycle and related to market amounts in Western Europe. Positive figures represent an energy saving realised by plastic products (less energy consumed by plastic products than by alternative materials). In the first part of the table figures are presented for all case studies analysed. In the second part of the table the results are aggregated for the most important application sectors.

Results of case studies analysed	**market share of case study**	**% of total energy saving**	**Total L.C.-Energy**		
			Plastics		**Alternat.**
			MJ/kg pl.	Mill GJ/a	Mill GJ/a
small packaging	2,45%	4%	34	32	65
beverage bottles	4,57%	**15%**	70	122	255
other bottles	5,95%	**5%**	29	65	110
other rigid packaging	11,18%	-5%	29	123	77
shrink and stretch films	5,85%	**25%**	43	97	318
carrier bags	1,13%	2%	68	29	44
other flexible packaging	6,13%	4%	18	42	76
big drain and sewer pipes	1,69%	0%	81	52	50
small drain and sewer p.	1,69%	2%	76	49	67
big drinking water pipes	0,73%	0%	84	23	25
small drinking water pipes	0,73%	2%	79	22	41
agricultural pipes	0,62%	1%	76	18	25
conduit pipes	0,55%	2%	74	16	32
gas pipes	0,35%	2%	71	9	30
heating and plumbing p.	0,28%	0%	81	9	9
industry pipes	0,28%	1%	81	9	15
insulation	3,76%	0%	95	137	136
flooring	1,23%	-2%	126	59	44
windows	2,16%	**7%**	679	559	623
housing	1,05%	3%	111	44	72
insulation in refrig.	0,14%	**11%**	4.657	256	354
under the hood	1,45%	**5%**	340	188	235
exterior and cockpit	0,96%	4%	340	124	159
other automotive parts	0,77%	3%	321	95	120
keep fresh boxes	1,50%	1%	110	63	67
buckets	0,50%	0%	110	21	25
waste bins	0,50%	0%	52	10	13
garden furniture	1,40%	**7%**	111	59	121
matresses	0,60%	0%	98	22	26
syringes	0,19%	-1%	112	8	3
infusion containers	0,14%	1%	63	3	8
soles	0,50%	0%	92	18	18

Results of case studies analysed	**market share of case study**	**% of total energy saving**	**Total L.C.-Energy**		
			Plastics		**Alternat.**
			MJ/kg pl.	Mill GJ/a	Mill GJ/a
Packaging	37,27%	**49%**	36	510	945
Building - Pipes	6,92%	**10%**	78	207	294
Building - Non Pipes	7,15%	**6%**	277	755	803
Electric/electronic	1,20%	**14%**	658	301	426
Automotive	3,18%	**12%**	336	407	514
Housewares	2,50%	1%	98	94	105
Furniture	2,00%	**7%**	107	82	147
Medicine	0,32%	0%	91	11	11
Footwear	0,50%	0%	92	18	18
Total	61,04%	**100%**	102	2.383	3.264

Table 108: The table above shows for case studies analysed and for most important application sectors: market shares on the total market of plastic products; relative contribution of each case study to the total energy saving by plastic products; total life-cycle energy demands of plastic products and products made of alternative materials.

Results of	**GHG emission savings**				**% of total**	**Total L.C.-GHG-Emissions**		
case studies	kt/a	kt/a	kt/a	kt/a	**GHG**	**Plastics**		**Alternat.**
analysed	Total	Production	Use	Waste M.	**saving**	g/kg pl.	kt/a	kt/a
small packaging	2.921	1.031	233	1.657	3%	113	106	3.027
beverage bottles	8.773	5.730	1.526	1.517	**10%**	4.058	7.074	15.848
other bottles	6.996	6.146	566	284	**8%**	41	92	7.088
other rigid packaging	2.048	-3.140	1.063	4.125	2%	-105	-448	1.600
shrink and stretch films	16.619	9.133	0	7.486	**20%**	1.352	3.018	19.637
carrier bags	1.044	127	0	917	1%	2.192	944	1.987
other flexible packaging	4.188	667	583	2.938	5%	-1.385	-3.236	952
big drain and sewer pipes	1.061	1.061	0	0	1%	2.653	1.714	2.775
small drain and sewer p.	2.237	2.344	0	-107	3%	2.631	1.700	3.937
big drinking water pipes	894	894	0	0	1%	2.623	726	1.620
small drinking water pipes	1.963	2.114	0	-151	2%	2.621	726	2.689
agricultural pipes	822	861	0	-39	1%	2.631	624	1.446
conduit pipes	1.562	1.564	0	-1	2%	2.601	549	2.111
gas pipes	1.624	1.655	0	-31	2%	2.379	314	1.938
heating and plumbing p.	256	322	0	-67	0%	2.788	294	550
industry pipes	590	688	0	-97	1%	2.880	304	894
insulation	1.322	1.265	0	57	2%	3.852	5.518	6.840
flooring	1.034	-1.081	0	2.115	1%	5.088	2.395	3.428
windows	5.432	-171	4.201	1.402	**6%**	41.555	34.211	39.643
housing	1.658	1.269	0	388	2%	4.778	1.919	3.577
insulation in refrig.	4.348	-142	4.491	-2	**5%**	206.616	11.364	15.711
under the hood	4.156	280	4.582	-705	5%	22.329	12.361	16.518
exterior and cockpit	3.293	-6	3.608	-309	4%	22.101	8.062	11.356
other automotive parts	1.725	91	1.820	-186	2%	21.506	6.335	8.060
keep fresh boxes	1.027	913	0	114	1%	4.647	2.657	3.684
buckets	675	782	0	-107	1%	4.649	886	1.561
waste bins	404	580	0	-175	0%	1.873	357	761
garden furniture	5.033	3.637	0	1.396	**6%**	4.615	2.463	7.496
matresses	-218	-177	0	-41	0%	4.591	1.050	833
syringes	-220	-310	107	-17	0%	4.712	336	115
infusion containers	397	396	0	1	0%	2.557	133	530
soles	145	118	0	28	0%	2.826	538	683

Results of	**GHG emission savings**				**% of total**	**Total L.C.-GHG-Emissions**		
case studies	kt/a	kt/a	kt/a	kt/a	**GHG**	**Plastics**		**Alternat.**
analysed	Total	Production	Use	Waste M.	**saving**	g/kg pl.	kt/a	kt/a
Packaging	42.588	19.692	3.971	18.925	**51%**	531	7.550	50.138
Building - Pipes	11.009	11.502	0	-493	**13%**	2.636	6.951	17.959
Building - Non Pipes	7.788	13	4.201	3.574	**9%**	15.450	42.123	49.911
Electric/electronic	6.005	1.127	4.491	387	**7%**	29.089	13.283	19.288
Automotive	9.174	365	10.010	-1.200	**11%**	22.060	26.759	35.933
Housewares	2.106	2.275	0	-169	3%	4.093	3.900	6.007
Furniture	4.815	3.460	0	1.355	**6%**	4.608	3.513	8.329
Medicine	177	86	107	-16	0%	3.805	468	645
Footwear	145	118	0	28	0%	2.826	538	683
Total	83.808	38.638	22.779	22.390	**100%**	4.516	105.086	188.894

Table 109: *Difference in GHG emissions of plastic products compared to alternative materials (mix of possible substitutes) within the total life cycle and related to market amounts in Western Europe. Positive figures represent a saving of GHG emissions realised by plastic products (less GHG emissions caused by plastic products than by alternative materials). In the first part of the table figures are presented for all case studies analysed. In the second part of the table the results are aggregated for the most important application sectors.*

Additionally, the table above shows for case studies analysed and for most important application sectors: relative contribution of each case study to the total GHG emission saving by plastic products; total life-cycle GHG emissions of plastic products and of products made of alternative materials.

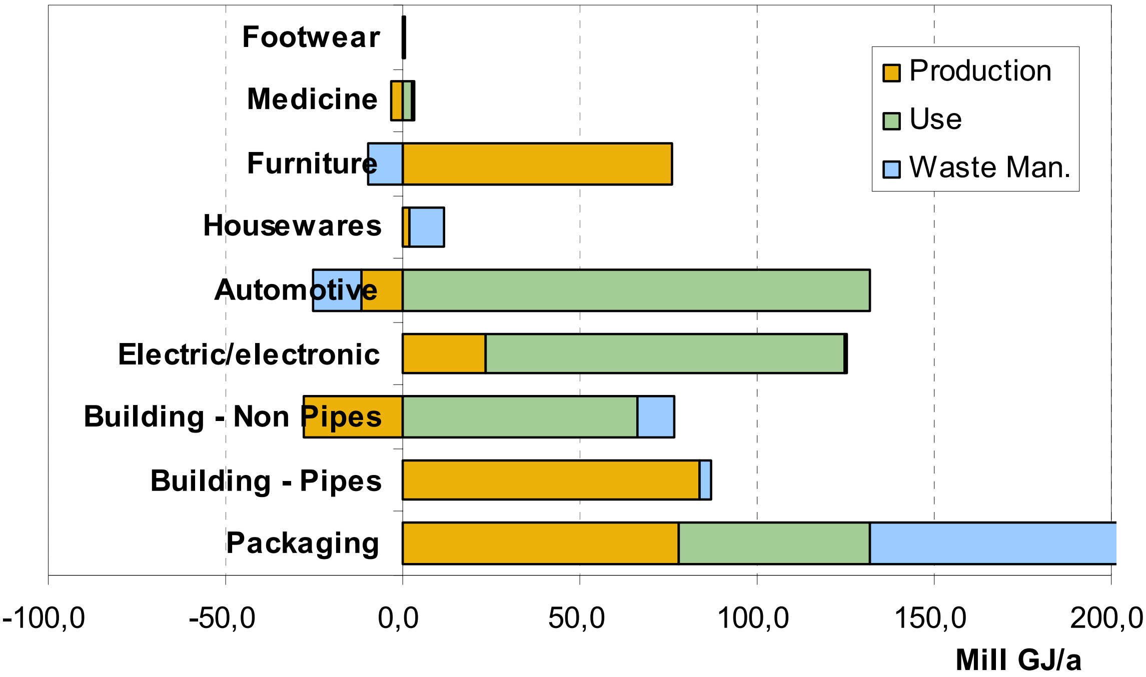

Figure 11: *Energy savings (+) and additional energy demand (–) of plastic products compared to alternative materials, split into contributions of the life-cycle phases production, use and waste management. The total result for plastic packaging is 435 Mill GJ/a.*

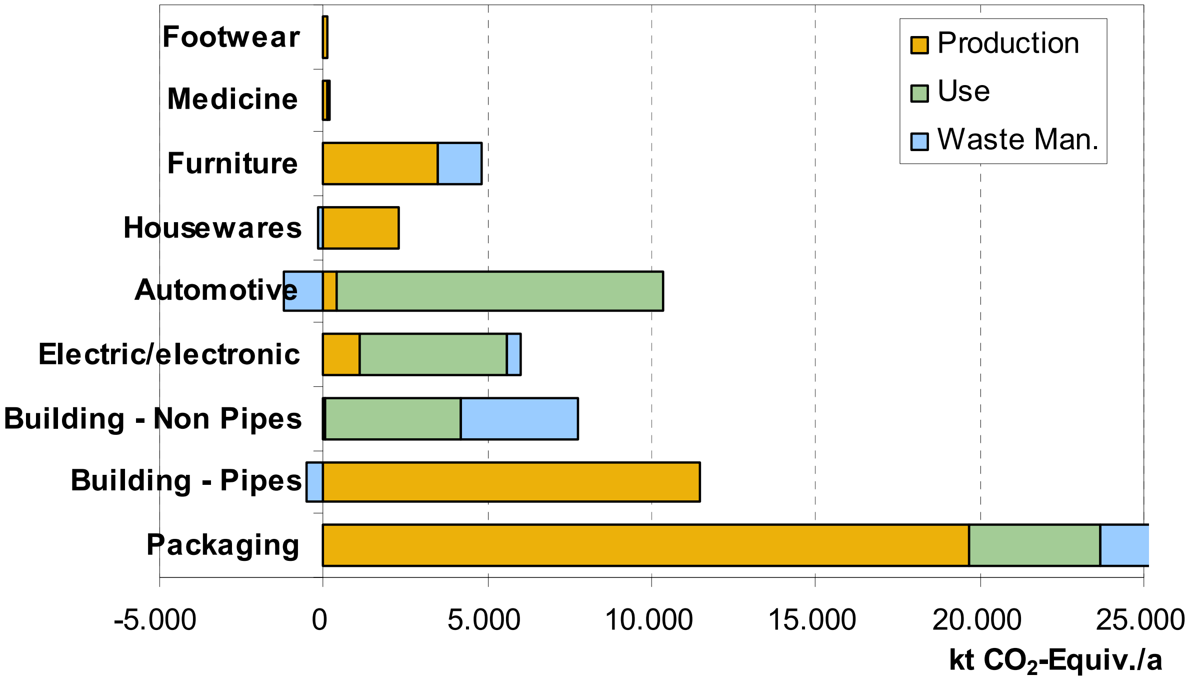

Figure 12: *GHG emission savings (+) and additional GHG emissions (–) of plastic products compared to alternative materials, split into contributions of the life-cycle phases production, use and waste management. The total result for plastic packaging is 42.600 kt CO_2-equivalents/a.*

The tables above show that the plastic products analysed need **880 Mill GJ less energy** per year and cause **83.800 kt less GHG emissions** per year within their total life-cycle in Western Europe than alternative products needed for a theoretical substitution.

The results show that plastic packaging realise about 50 % of the total benefits of plastic products (50 % of energy savings, 51 % of GHG emission savings). Interestingly, the data used show about the same (9 % less) demand of non-renewable fuels to produce plastics packaging or packaging made of other materials. Additionally, the production of alternative packaging materials consumes a high amount of renewable fuels, which are mostly wood and wood residues used within paper production. The saving of GHG emissions by plastic packaging is mainly caused by CH_4 emissions from paper and wood in landfills.

Plastic products used in the sectors building (pipes and other applications), electric / electronic, automotive and furniture lead to similar contributions to total savings of about 6 – 14 % each, whereas the influence of housewares, medical products and shoe soles is very small.

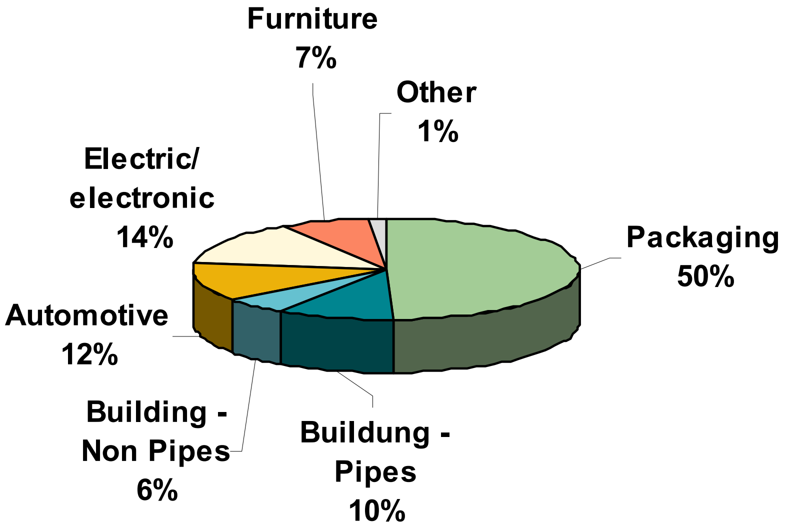

Figure 13: Relative contributions of application sectors to total energy savings

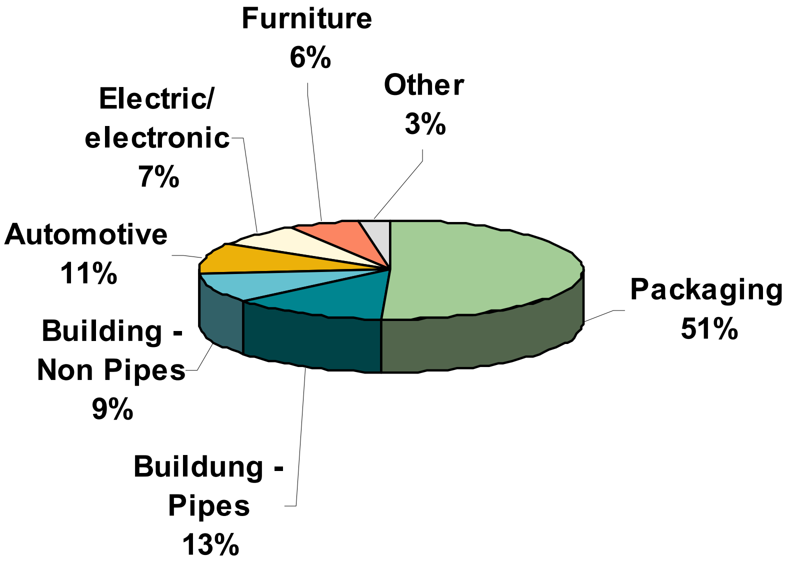

Figure 14: Relative contributions of application sectors to total GHG emission savings

The tables also show that 25 % of the *difference* in the total life cycle energy of plastic products and alternative materials are related to primary production, 40 % to the use-phase and 35 % to the waste management phase (46 %, 27 % and 27 % for GHG emissions). Especially in the packaging sector these figures are influenced by the definition of primary production processes, which consume considerable amounts of recycled waste for glass, corrugated board, paper, cardboard and tin plate. If these primary production processes would be defined with less or no recycling share (the calculation model would then consider higher effects of recycling within waste management), the relative contribution of primary production to the total benefits of plastics would significantly increase whereas the relative contribution of waste management would decrease.

Beside the influence of different materials on the total energy demand of a product there are also many other possibilities to optimise energy consumption in product systems or processes (see chapters 2.2.1and 6). For the general discussion about optimisation of energy consumption it is important to know, which life cycle phase causes the highest energy demand. Very often the **use-phase** is very important or even the most important life-cycle phase regarding total energy demand:

In this study, effects in use were quantified for automotive parts, insulation materials (including insulation in refrigerators and window frames) and packaging materials (avoided food losses and energy demand for transport), with considerable contributions to the total savings in the same order (highest impact by automotive parts; rather small use effects for plastic packaging).

The tables and figures above only show the *difference* of energy demand in the use phase of plastic products and alternatives. This difference is derived from the *total energy demand of the use phase* for certain products. An analysis of these *total, absolute* results (before calculation of the differences between plastics and other materials) shows that approx. 36 % of the total average life-cycle energy demand of plastic products is linked to the use phase. For alternative materials, approx. 41 % of the total life-cycle energy effects are within the use phase.

If the analysis only considers those plastic products that actually show effects in the use phase (packaging, insulation and automotive products; they represent about 68% of the market covered by case studies in this model), then the use phase covers approx. 50 % of the total average life-cycle energy effects of plastics (or 58 % for alternative materials).

The figures regarding the relevance of the use phase given above are only based on the use-effects that were quantified in this study. An additional effect of the use phase of almost every product is different handling of the product, leading to different lifetimes. Consideration of such effects in calculations will even increase the proportion of the use phase within the total life-cycle energy demand.

5.3 Sensitivity analysis

The following chapter is dealing with an estimation of the uncertainty of the total result. After that some selected sensitivity investigations are carried out in detail.

5.3.1 Estimation of the uncertainty of the total result

The following estimation of the uncertainty of the total result regarding energy savings by plastic products concentrates on the *main* uncertainties within the data used for calculation. These are generally uncertainties within the data on mass ratios (including definition of functional units, market shares of alternative materials and lifetime assumptions), on use effects and regarding the assumptions that the products analysed in a case study are representative for a certain sector of the total market.

Compared to the influences listed above, the uncertainties within energy data for production and waste treatment of one kg plastics or alternative material are considered to be very low. Possible changes of the result (e.g. due to an elimination of methodical differences in different studies for different materials) will be quite random and will not influence the total result much.

Table 110 and Table 111 show how the uncertainty of the total result is estimated. The calculation follows three steps:

1. The uncertainty of the mass ratio for the products of a certain case study is estimated. Based on the estimated uncertainty, a possible range of the energy demand of alternative materials (per kg substituted plastics) is calculated for the life-cycle phases production and waste management. Further on, a range for the difference in the energy demand of plastics and other materials for production and waste management is derived.
2. The uncertainty of data used for the use phase is estimated. This uncertainty is then already combined with the difference of the energy demand of plastics and other materials in the use phase, because the data used influence the use-phase energy for plastics and for other materials in the same way (e.g. fuel demand per kg mass used in cars; heating or cooling energy needed for various insulation materials, etc.). The resulting possible range of results, together with the range for production and waste management calculated above, lead to an optimistic an a pessimistic value for the total energy savings by plastics in each case study.

3. Thirdly, the uncertainty regarding the representativeness of the products assessed in the case study for a total market segment is assumed. This step enlarges the range of possible results for the energy savings by each case study once more. Based on these values, the ranges in Mill GJ/a for Western Europe are calculated in the same way as the respective results in chapter 5.2.

Before the uncertainty ranges are calculated for each investigated case study, the assumptions regarding uncertainties are discussed for those case studies, which cover about 80 % of the total uncertainty.

Uncertainties of mass ratios:

Small drain and sewer pipes: Mass ratios for stoneware pipes are about 3 times higher in a study dealing with 250 mm diameter pipes than in a study dealing with 150 mm diameter pipes. For other materials only one reference was available. Due to the wide range given above, it is assumed that the (average) values chosen for the calculation have an uncertainty of ± 50 %.

Data on masses for garden furniture, housings and keep fresh boxes are only based on investigations of selected examples. Additionally, rough market shares of alternative materials were only available for garden furniture and had to be estimated for housings and keep fresh boxes. Therefore a rather high uncertainty for mass ratios was assumed (± 30 %).

Automotive parts: Average mass ratio values used in this study are 1,5 for steel, 1,2 for aluminium profiles and 1,5 for pressure die-casting aluminium. Mass ratios for single components can vary between 1,2 – 4,0 for steel and 1,2 – 3,0 for aluminium. Data on selected aluminium parts given by Mavel show a mass ratio which is about 33 % lower than the mass ratio used in this study. For the estimation of the uncertainty of the total result, an average uncertainty of ± 30 % is assumed for all mass ratios in the automotive sector.

The uncertainty given for flooring is not related to the mass ratio, but in this case to the energy data used for Linoleum, where different studies show values with a difference of about 30 % (see chapter 4.3.2.2).

The uncertainty of 20 % assumed for windows is mainly associated with market data of alternative materials (aluminium, wood, combinations, etc.).

Beverage bottles: Specific masses of beverage packaging changed considerably within the last 10 years due to constant optimisation of packaging materials. Older and more recent studies reflect these differences in the specific mass of beverage packaging: 23 – 26 g/l for PET one-way, 56 – 70 g/l for PET refillable, 24 – 37 g/l for aluminium cans and 62 – 80 g/l for tin plate cans. For the average values used in this study, an uncertainty of ± 20 % is assumed, as not all fillers change immediately to the lightest packaging material.

Finally, the uncertainties for mass ratios in other packaging case studies are assumed to be low (± 10 %), due to the detailed database on packaging materials from which they are derived. Also the mass ratio for insulation materials in refrigerators is considered to be quite accurate, because it is directly derived from the difference in density of the materials.

Uncertainty of use effects:

Food losses: Data on the average energy needed to produce food was available, but the amount of food saved due to plastic packaging (in comparison with other packaging materials) had to be assumed (30 % of relevant food packaging save 5 % losses of the food packed). An uncertainty of ± 50 % is assumed.

The uncertainty of other effects in the use phase is assumed to be ± 10 %:

Mass related fuel demand in the automotive sector: In the view of the range of data used in various studies, the value used in this study has been selected carefully and in a way that the calculations are conservative from the perspective of plastics.

In the same way, the difference of k-values of plastic and non plastic window frames was assumed to be rather low compared to values used in different studies.

The calculation of the different energy demand of refrigerators and freezers with different insulation materials was based on recent data on electricity consumption and the insulating properties of the materials. Additionally, the lifetime of the appliances was also assumed in a conservative way (10 years).

Uncertainty of representativeness of case study

The worst representativeness is assumed for the case study “housings” for electric and electronic appliances (± 50 %). On the one hand, the exact amount of plastics used for housings is not known. On the other hand, the current market shows only very few examples for housings made of other materials. Therefore several assumptions had to be made.

For garden furniture and keep fresh boxes some data were available, but again the market share of products represented by these case studies had to be estimated. An uncertainty of ± 40 % is assumed.

For refrigerators and small drain and sewer pipes the variety of products (regarding diameter, thickness of material, dimensions of the appliance, thickness of the insulation, etc.) is certainly more complex than the average data used for the case study calculations. Additionally to the uncertainty already given for the mass ratios used, ± 20 % are assumed as uncertainty that the average values used do not represent the actual average conditions of all products on the market.

As the data on automotive parts is based on detailed investigations of four cars, each representing a different class (upper class, high and low medium class, lower class), a lower uncertainty regarding representativeness was assumed as in the case studies listed before (± 15 %). Again, the uncertainty assumed for mass ratios contribute to the total uncertainty as well.

Finally, only 5 % uncertainty regarding representativeness was assumed for the packaging case studies because of the high amount of market data available.

Calculation of total uncertainty ranges

In the calculation of the results, the values for production, use and waste management are added, but the total value is then *multiplied* with the market share of products represented by a case study. Therefore the assumed uncertainty ranges have to be modified for the calculation described above. A confidence interval of 90 % for multiplied values can be estimated by the sum of the confidence intervals of 68 %:

NOT[1-68%] AND NOT[1-68%] = NOT[1-90%] or 0,32 x 0,32 = 0,10

Therefore, all values for uncertainties listed in the tables below are multiplied with 0,99/1,64 = ***0,6***, which is the ratio of the 68%-interval (± 0,99) and the 90%-interval (± 1,64) of the Gaussian distribution, before they are used to calculate uncertainty ranges (min – max or pessimistic – optimistic).

Example: Calculation of the uncertainty range for “small packaging”:

To produce & recover small plastic packaging, 85,3 MJ/kg are consumed. The respective energy demand for alternative materials is 111,7 MJ/kg. The uncertainty for the mass ratio is assumed to be 5 %. Therefore the energy demand to produce & recover alternative materials can vary between 111,7 x (1 + 0,05 x ***0,6***) and 111,7 x (1 - 0,05 x ***0,6***), that is between 108,3 and 115,0 MJ/kg. Consequently, the difference to the energy demand to produce & recover small plastic packaging can vary between 23,0 and 29,8 MJ/kg.

The difference between plastics and other materials in the use-phase of small packaging is 3,5 MJ/kg plastics. The uncertainty of this difference is assumed to be 50 %. Therefore the total energy savings can vary between 23,0 + 3,5 x (1 + 0,5 x ***0,6***) and 23,0 + 3,5 x (1 - 0,5 x ***0,6***), that is between 25,5 and 34,3 MJ/kg. The average saving is 29,9 MJ/kg.

Finally the uncertainty regarding the representativeness of the case study for the product group is assumed to be 5 %. Therefore the total energy savings can vary between 25,5 – 29,9 x (0,05 x ***0,6***) and 34,3 + 29,9 x (0,05 x ***0,6***), that is between 24,6 and 35,2 MJ/kg.

	prod. & waste energy plastics MJ/kg	prod. & waste energy other materials MJ/kg	uncertainty of mass ratio for products in case study ± %	prod. & waste energy other mat. MIN MJ/kg	prod. & waste energy other mat. MAX MJ/kg	difference in prod. & waste energy MIN MJ/kg	difference in prod. & waste energy MAX MJ/kg
small packaging	85,3	117,4	5%	113,8	120,9	28,6	35,6
beverage bottles	56,5	121,4	20%	106,7	136,0	50,3	79,6
other bottles	79,6	96,1	10%	90,3	101,9	10,7	22,3
other rigid packaging	79,7	65,5	10%	61,5	69,4	-18,1	-10,2
shrink and stretch films	43,5	142,4	10%	133,8	151,0	90,3	107,5
carrier bags	68,1	103,0	5%	99,9	106,1	31,7	37,9
other flexible packaging	68,8	79,9	10%	75,1	84,7	6,2	15,9
big drain and sewer pipes	81,0	77,4	30%	63,4	91,4	-17,6	10,5
small drain and sewer pipes	76,2	104,0	50%	72,6	135,4	-3,6	59,2
big drinking water pipes	83,8	90,4	30%	74,0	106,8	-9,8	23,0
small drinking water pipes	78,8	149,7	20%	131,6	167,8	52,9	89,0
agricultural pipes	76,2	104,0	30%	85,1	122,8	9,0	46,6
conduit pipes	74,4	152,0	20%	133,6	170,3	59,2	95,9
gas pipes	70,9	224,8	20%	197,7	251,9	126,8	181,0
heating and plumbing pipes	81,1	80,9	20%	71,1	90,6	-10,0	9,5
industry pipes	81,1	145,7	20%	128,1	163,3	47,1	82,3
insulation	95,3	95,1	10%	89,4	100,8	-5,9	5,5
flooring	126,0	94,4	30%	77,3	111,5	-48,7	-14,5
windows	72,5	69,4	20%	61,0	77,7	-11,5	5,2
housing	110,7	178,9	30%	146,5	211,3	35,8	100,6
insulation in refrigerators	101,7	39,1	10%	36,7	41,5	-65,0	-60,3
under the hood	112,4	86,9	30%	71,1	102,6	-41,3	-9,8
exterior and cockpit	112,6	78,6	30%	64,4	92,8	-48,3	-19,8
other automotive parts	93,7	98,2	30%	80,4	116,0	-13,3	22,3
keep fresh boxes	109,9	117,9	30%	96,5	139,2	-13,4	29,3
buckets	110,0	131,7	20%	115,8	147,6	5,8	37,6
waste bins	51,6	67,5	10%	63,4	71,6	11,8	19,9
garden furniture	111,0	226,9	30%	185,8	268,0	74,8	157,0
matresses	97,9	115,2	10%	108,3	122,2	10,3	24,3
syringes	112,3	1,9	5%	1,9	2,0	-110,5	-110,4
infusion containers	62,6	163,4	10%	153,5	173,3	90,9	110,7
soles	92,0	94,1	5%	91,2	96,9	-0,8	4,9

Table 110: Estimation of the uncertainty of the total result for energy savings by plastic products in comparison with other materials. The table above shows step 1 of the procedure explained above.

	difference in energy demand of USE phase MJ/kg	uncertainty of use effects ± %	energy saving by plastics pessimistic MJ/kg	energy saving by plastics optimistic MJ/kg	uncertainty of representativeness of case study ± %	energy saving by plastics pessimistic MJ/kg	energy saving by plastics optimistic MJ/kg
small packaging	3,4	50%	30,9	40,1	5%	29,9	41,1
beverage bottles	11,6	50%	58,3	94,6	5%	56,0	96,9
other bottles	3,4	50%	13,1	26,7	5%	12,5	27,3
other rigid packaging	3,4	50%	-15,8	-5,8	5%	-15,5	-6,1
shrink and stretch films	0,0		90,3	107,5	5%	87,3	110,5
carrier bags	0,0		31,7	37,9	5%	30,7	39,0
other flexible packaging	3,4	50%	8,6	20,3	5%	8,2	20,7
big drain and sewer pipes	0,0		-17,6	10,5	20%	-17,1	10,0
small drain and sewer pipes	0,0		-3,6	59,2	20%	-7,0	62,5
big drinking water pipes	0,0		-9,8	23,0	20%	-10,6	23,8
small drinking water pipes	0,0		52,9	89,0	20%	44,3	97,6
agricultural pipes	0,0		9,0	46,6	20%	5,6	50,0
conduit pipes	0,0		59,2	95,9	20%	49,8	105,3
gas pipes	0,0		126,8	181,0	20%	108,2	199,6
heating and plumbing pipes	0,0		-10,0	9,5	20%	-10,0	9,5
industry pipes	0,0		47,1	82,3	20%	39,3	90,1
insulation	0,0		-5,9	5,5	20%	-5,9	5,5
flooring	0,0		-48,7	-14,5	10%	-46,8	-16,4
windows	80,5	10%	64,1	90,5	10%	59,4	95,2
housing	0,0		35,8	100,6	50%	15,2	121,2
insulation in refrigerators	1841,4	10%	1665,2	1892,3	20%	1450,5	2107,0
under the hood	109,2	10%	61,3	106,0	15%	53,8	113,6
exterior and cockpit	130,5	10%	74,4	118,6	15%	65,6	127,3
other automotive parts	81,5	10%	63,4	108,8	15%	55,6	116,6
keep fresh boxes	0,0		-13,4	29,3	40%	-15,3	31,2
buckets	0,0		5,8	37,6	30%	1,9	41,6
waste bins	0,0		11,8	19,9	20%	9,9	21,8
garden furniture	0,0		74,8	157,0	40%	46,8	185,0
matresses	0,0		10,3	24,3	30%	7,2	27,4
syringes	33,8		-76,7	-76,6	10%	-72,1	-81,2
infusion containers	0,0		90,9	110,7	30%	72,7	128,9
soles	0,0		-0,8	4,9	30%	-1,1	5,3

Table 111: Estimation of the uncertainty of the total result for energy savings by plastic products in comparison with other materials. The table above shows step 2 and 3 of the procedure explained above.

	energy saving Western Europe pessimistic Mill GJ/a	energy saving Western Europe AVERAGE Mill GJ/a	energy saving Western Europe optimistic Mill GJ/a	average deviation from average value (± X) Mill GJ/a	relative contribution to total deviation %
small packaging	27,9	33,1	38,4	5,3	1,5%
beverage bottles	97,7	133,3	169,0	35,6	**10,2%**
other bottles	28,3	45,1	62,0	16,9	**4,8%**
other rigid packaging	-65,9	-46,0	-26,2	19,8	**5,7%**
shrink and stretch films	194,9	220,7	246,6	25,8	**7,4%**
carrier bags	13,2	15,0	16,8	1,8	0,5%
other flexible packaging	19,0	33,7	48,4	14,7	**4,2%**
big drain and sewer pipes	-11,1	-2,3	6,5	8,8	2,5%
small drain and sewer pipes	-4,5	18,0	40,4	22,4	**6,4%**
big drinking water pipes	-2,9	1,8	6,6	4,8	1,4%
small drinking water pipes	12,3	19,6	27,0	7,4	2,1%
agricultural pipes	1,3	6,6	11,9	5,3	1,5%
conduit pipes	10,5	16,4	22,2	5,8	1,7%
gas pipes	14,3	20,3	26,3	6,0	1,7%
heating and plumbing pipes	-1,1	0,0	1,0	1,0	0,3%
industry pipes	4,1	6,8	9,5	2,7	0,8%
insulation	-8,5	-0,3	7,9	8,2	2,3%
flooring	-22,0	-14,9	-7,7	7,1	**2,0%**
windows	48,9	63,6	78,4	14,7	**4,2%**
housing	6,1	27,4	48,7	21,3	**6,1%**
insulation in refrigerators	79,8	97,8	115,9	18,1	**5,2%**
under the hood	29,8	46,3	62,9	16,6	**4,7%**
exterior and cockpit	23,9	35,2	46,4	11,3	**3,2%**
other automotive parts	16,4	25,4	34,3	9,0	**2,6%**
keep fresh boxes	-8,8	4,5	17,9	13,3	**3,8%**
buckets	0,4	4,1	7,9	3,8	1,1%
waste bins	1,9	3,0	4,2	1,1	0,3%
garden furniture	25,0	61,9	98,7	36,9	**10,5%**
matresses	1,6	4,0	6,3	2,3	0,7%
syringes	-5,1	-5,5	-5,8	-0,3	-0,1%
infusion containers	3,8	5,2	6,7	1,5	0,4%
soles	-0,2	0,4	1,0	0,6	0,2%
Total	**531,0**	**880,4**	**1229,9**	**349,5**	**100%**

Table 112: Estimated range of uncertainty of the total result for energy savings by plastic products in comparison with other materials. The average deviation given above describes the magnitude of the uncertainty range around the mean value (± X) and is equal to (optimistic result – pessimistic result) / 2.

The table above shows the final estimated range of uncertainty of the total result for energy savings by plastic products in comparison with other materials, which is ± 40 % of the main result of 880 Mill GJ/a.

The last two columns show the relative contributions of the case studies to the total uncertainty. In the following table, the case studies have been sorted according to their relative contribution to the total uncertainty (the table shows the case studies with a total contribution of approx. 80 % to the total uncertainty).

	uncertainty of mass ratio for products in case study	uncertainty of use effects	uncertainty of represen-tativeness of case study	energy saving Western Europe pessimistic	energy saving Western Europe optimistic	average deviation	relative contribution to total deviation
	± %	± %	± %	Mill GJ/a	Mill GJ/a	Mill GJ/a	%
garden furniture	30%	0%	40%	25,0	98,7	36,9	**10,5%**
beverage bottles	20%	50%	5%	97,7	169,0	35,6	**10,2%**
shrink and stretch films	10%	0%	5%	194,9	246,6	25,8	**7,4%**
small drain and sewer pipes	50%	0%	20%	-4,5	40,4	22,4	**6,4%**
housing	30%	0%	50%	6,1	48,7	21,3	**6,1%**
other rigid packaging	10%	50%	5%	-65,9	-26,2	19,8	**5,7%**
insulation in refrigerators	10%	10%	20%	79,8	115,9	18,1	**5,2%**
other bottles	10%	50%	5%	28,3	62,0	16,9	**4,8%**
under the hood	30%	10%	15%	29,8	62,9	16,6	**4,7%**
windows	20%	10%	10%	48,9	78,4	14,7	**4,2%**
other flexible packaging	10%	50%	5%	19,0	48,4	14,7	**4,2%**
keep fresh boxes	30%	0%	40%	-8,8	17,9	13,3	**3,8%**
exterior and cockpit	30%	10%	15%	23,9	46,4	11,3	**3,2%**
other automotive parts	30%	10%	15%	16,4	34,3	9,0	**2,6%**
big drain and sewer pipes	30%	0%	20%	-11,1	6,5	8,8	**2,5%**
Total							**82%**

Table 113: Case studies with the highest contributions to the total uncertainty, sorted in descending order. The case studies above the middle line cover 51 % of the total uncertainty, all case studies listed cover 82 % of the total uncertainty.

5.3.2 Selected sensitivity investigations

Waste management scenarios:

As an alternative to the current conditions of waste management (base case), a “future case” with less landfilling, increased energy recovery and slightly increased recycling rates was assumed (for details see chapter 3.4.2).

The final results in the base case are: 880 Mill GJ saved energy consumption and 83.800 kt saved CO_2-equivalents in Western Europe per year. The results based on the future case are 930 Mill GJ/a (+ 5,2 %) and 65.900 kt CO_2-equivalents/a (– 21 %). The main reasons for the changes are: Plastics profit more from less landfilling and increased energy recovery than the average mix of other materials. On the other hand, less landfilling reduces CH_4 emissions from paper and wood in landfills substantially. Additionally, more carbon in plastics is converted to CO_2, and the substituted processes to produce power and steam sometimes have a higher efficiency. This leads to the reduction of the benefit of plastics regarding GHG emissions.

Results without assuming saved food losses in general, only including differences in food savings between plastics and other packaging materials:

Potential effects in the use phase of *packaging in general* are saved food losses due to the use of packaging (compared to distribution of goods without packaging). In this study it was assumed that 70 % of all food packaging (plastics and other materials) prevent the loss of 20 % of the food packed.

In addition to this effect of *all* packaging materials, it was assumed that 20 % of the total food packaging made of plastics lead to an *extra 5 %* saving of food losses compared to a hypothetical scenario, where all plastic food packaging has been substituted by other materials. This extra saving is assumed because plastic food packaging often allows delivering food in portions better adapted to the need of the consumer and helps to keep food fresh for a longer time.

The tables below show the results of the calculation model, when only the additional food saving by plastic packaging is considered, but not the general effect for all packaging materials. This change does not affect the differences in energy demand and GHG emissions between plastics and alternatives. Only the values for the total life cycle of packaging materials change.

Results of case studies analysed	**Total L.C.-Energy**			**Total L.C.-GHG-Emissions**		
	Plastics		**Alternat.**	**Plastics**		**Alternat.**
	MJ/kg pl.	Mill GJ/a	Mill GJ/a	g/kg pl.	kt/a	kt/a
small packaging	82	76	110	3.605	3.366	6.287
beverage bottles	70	122	255	4.058	7.074	15.848
other bottles	76	173	218	3.533	8.016	15.012
other rigid packaging	76	325	279	3.387	14.439	16.487
shrink and stretch films	43	97	318	1.352	3.018	19.637
carrier bags	68	29	44	2.192	944	1.987
other flexible packaging	65	153	187	2.107	4.920	9.108
Total Packaging	69	976	1.411	2.941	41.777	84.365

Table 114: Energy demand and GHG emissions of packaging materials in their total life cycle, when only the additional food saving by plastic packaging, but not the general food saving effect of all packaging materials is included in the calculations.

Results without assuming additional food savings by plastic packaging:

If no additional savings of food losses are assumed for plastic packaging, the main results change to 847 Mill GJ/a (– 3,8 %) and 83.800 kt CO_2-equivalents/a (– 2,8 %).

Special assumptions for the electricity mix of aluminium production:

Koch & Harnisch [2002] has investigated, how the total CO_2 emissions of the primary production of aluminium change, if the sources of electricity for the European aluminium plants are considered in detail ("contract mix" instead of UCPTE mix). For aluminium produced in Western Europe, the CO_2 emissions decrease by 32 %, for total Europe (including Eastern Europe) they decrease by 22 %.

It is not clear to which extent such a “contract mix” has been considered by ETH & EMPA [1996]. If the CO_2 emissions of aluminium production used in this study are decreased by 30 %, the total savings change from 83.800 kt to 79.200 kt CO_2-equivalents/a (– 5,5 %).

Lower mass ratio for aluminium in the automotive sector

Data on selected aluminium parts given by Mavel show a mass ratio which is about 33 % lower than the mass ratio used in this study (see chapter 4.5.1.2 and uncertainty of mass ratios given above). If the mass ratio used is decreased by 33 %, the total energy saving in the automotive sector changes from 107 to 66 Mill GJ/a. The energy savings for the total market are 4,6 % lower and the GHG savings 3 % lower than the standard results.

	Energy saving Mill GJ/a	Relative change	GHG emission saving kt/a	Relative change
Standard results	**880**		**83.800**	
Slightly more recycling, more energy recovery, less landfilling	930	5,7%	65.900	-21,4%
Results without saved food losses due to plastic packaging	847	-3,8%	83.800	0,0%
Aluminium production with "contract mix" to produce electricity			79.200	-5,5%
Lower mass ratios for aluminium in the automotive sector	840	-4,5%	81.300	-3,0%

Table 115: Overview on results of selected sensitivity investigations.

A last general comment: During the calculations and sensitivity analyses performed in this study it was found out that the *big number* of case studies investigated makes the overall results quite stable, because variations in one case study become small from the perspective of the total market, and possible improvement of data shows a random distribution between plastics and alternative materials. Additionally, many assumptions were chosen in a conservative way, meaning that the consequential results are calculated in favour of alternative materials.

5.4 Conservative extrapolation of results to cover all substitutable plastic products

The case studies analysed and quantified in this calculation model cover about 75 % of the total amount of substitutable plastic products (81,4 % of all plastic products are estimated to substitutable, 61 % are covered by case studies). This chapter proposes a conservative extrapolation of the results for the case studies analysed to cover the total amount of substitutable plastic products.

To find a reasonable and conservative estimation for average possible results of substitutable plastic products not covered by case studies yet, the results for energy savings and GHG emissions savings calculated so far have been aggregated into classes (0 – 30 MJ/kg plastics, 30 – 60 MJ/kg plastics, etc.). The following figures show the sum of the market share of case studies within a certain class of result.

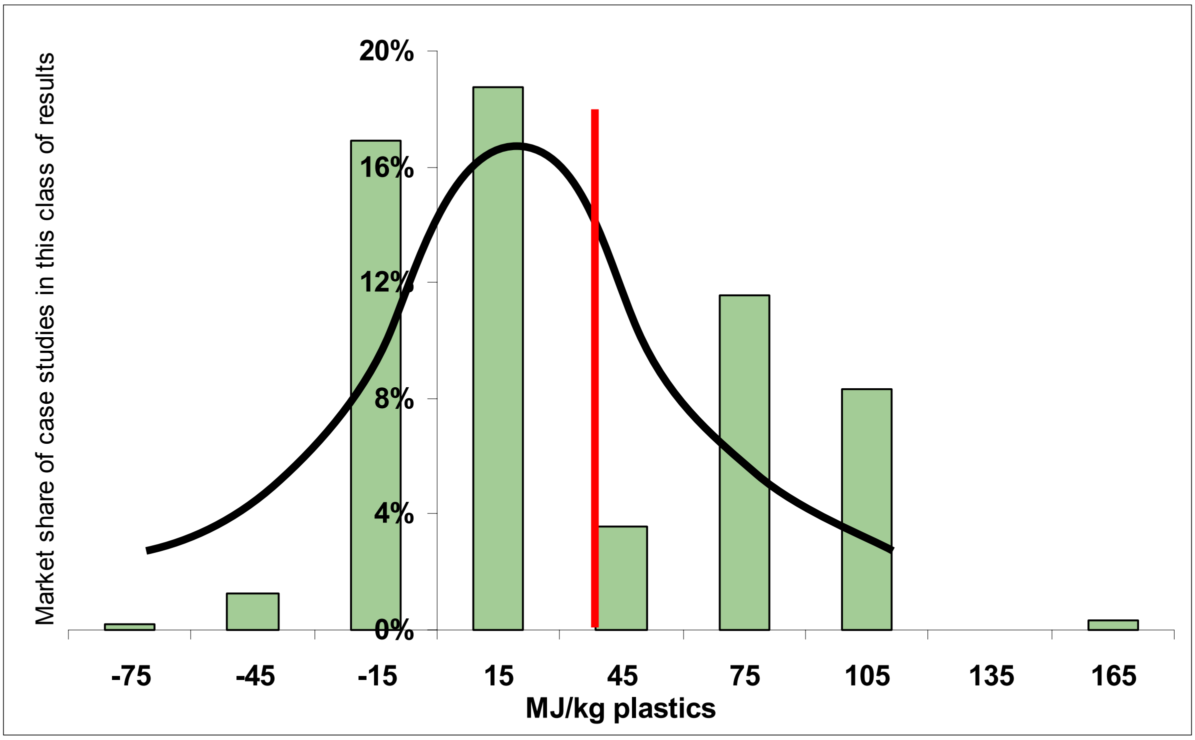

Figure 15: *Results of case studies for energy savings by plastic products, aggregated into classes with a range of 30 MJ/kg each. The figure shows the sum of the market share of case studies within a certain class of result (case studies with results higher than 180 MJ/kg are not shown). The red line shows the weighted average of the case studies calculated so far (38 MJ/kg plastics). The black line shows, how an assumed average value of 19 MJ/kg plastics for the remaining amount of substitutable plastic products would relate to the results calculated so far.*

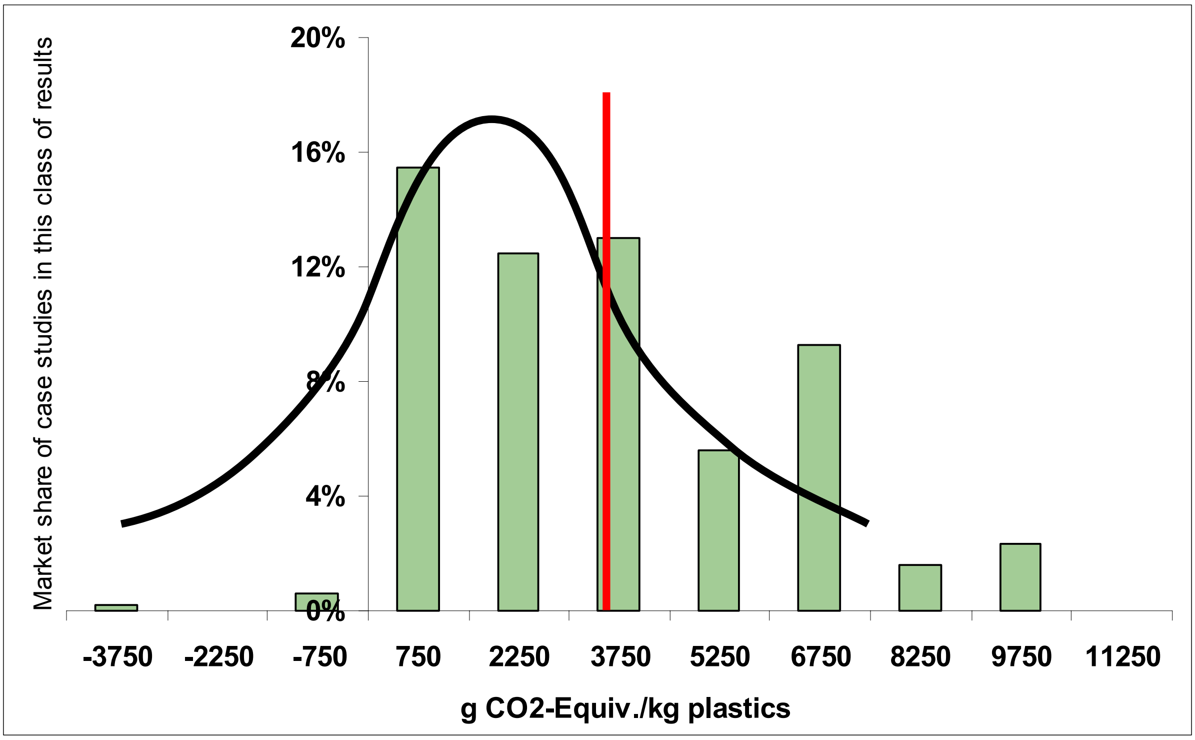

Figure 16: *Results of case studies for GHG emission savings by plastic products, aggregated into classes with a range of 500 g CO_2-equivalent/kg plastics each. The figure shows the sum of the market share of case studies within a certain class of result (case studies with results higher than 11.500 g/kg are not shown). The red line shows the weighted average of the case studies calculated so far (3.600 g CO_2-equivalent/kg plastics). The black line shows, how an assumed average value of 1.800 MJ/kg plastics for the remaining amount of substitutable plastic products would relate to the results calculated so far.*

Based on the figures above, two values – representing only 50 % of the weighted average results of the case studies calculated so far – are proposed as a conservative estimate for the remaining amount of substitutable plastic products: 19 MJ/kg plastics for energy savings and 1.800 g CO_2-equivalent/kg plastics for GHG savings. The figures above show that these values, representing an average value of possible results of further case studies, are a conservative assumption from the perspective of plastic products and in the view of the results calculated so far.

The additional energy and GHG saving resulting from the assumption above is calculated by

7.110 kt substitutable plastic products not covered so far x 19 GJ/t = 140 Mill GJ / a

7.110 kt x 1.800 t CO_2-equivalent / kt plastics = 12,8 Mt CO_2-equivalents / a.

5.5 Different ways to present and compare the results for the total market of plastic products

In this chapter, results relating to different segments of the total market of relevant products are presented. Figure 17 shows the four different segments of the total market that are used for the presentation of results.

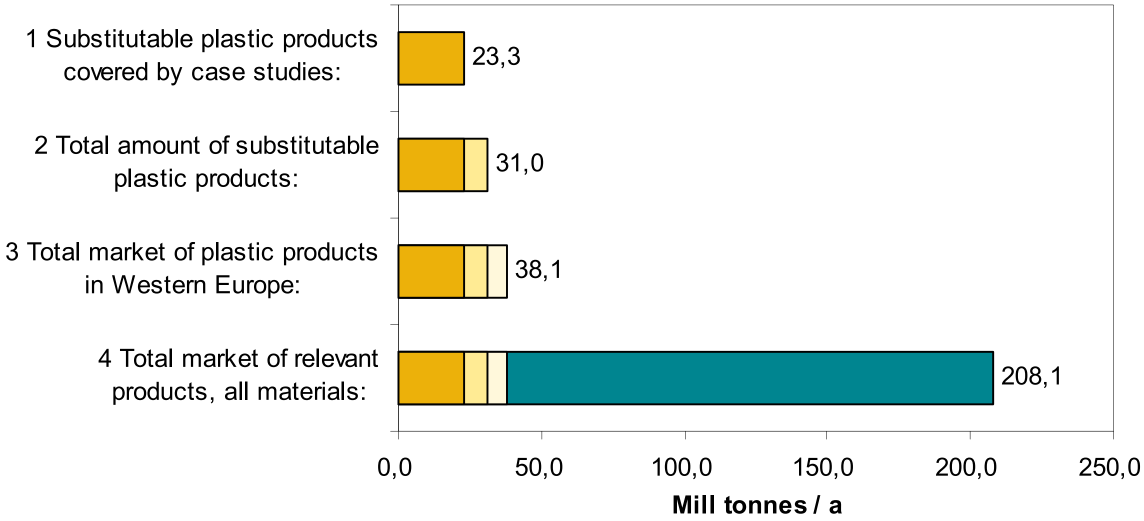

Figure 17: Different segments of the total market used to present the results.

1) Results for substitutable plastic products covered by the case studies analysed

The case studies analysed cover 61 % of the total market of plastic products or 75 % of all substitutable plastic products, that is equivalent to 23.270 kt/a. The total life cycle energy demand of the plastic products analysed is **2.380 Mill GJ/a** (or 102 GJ/t).

If the plastic products analysed in the case studies were substituted by alternative materials, the substituting products would have a mass of 89.730 kt/a (average mass ratio: 3,86). The total life cycle energy demand of these products would be **3.260 Mill GJ/a** (or 36 GJ/t).

Therefore, the “additional energy needed if plastic products would be substituted" or the "energy saved by plastic products” is **880 Mill GJ/a** (or 38 GJ/t plastic product). This absolute figure can be expressed as a percentage in two ways:

- If the plastic products analysed would be substituted, **37 %** more energy would be needed than in the total life cycle of these plastic products today.
- Plastic products enable to save **27 %** of the energy that would be needed, if no plastic products were available in the case studies analysed.

For GHG emissions, given in CO_2 equivalents, the bold values above are:

- Life cycle GHG emissions of the plastic products analysed: 105 Mt/a
- Life cycle GHG emissions of the products needed for substitution: 189 Mt/a
- Saving in GHG emissions: **84 Mt/a** (**80 %** more than emitted today or **44 %** less than in the case of substitution).

2) Estimated results for ALL substitutable plastic products

Results for ALL substitutable plastic products (81 % of total market of plastic products) can be estimated by the conservative extrapolation of the case study results presented in the chapter above. For the substitutable plastic products not covered by case studies yet, the energy saving was estimated at 140 Mill GJ/a and the GHG emission saving was estimated at 13 Mt CO_2 equivalents/a.

Therefore the “extrapolated results” are:

Total amount of substitutable plastic products: 31.000 kt/a; total life cycle energy demand of all substitutable plastic products is **3.170 Mill GJ/a** (or 102 GJ/t).

Total amount of products needed for substitution: 119.500 kt/a (Assumption: same average mass ratio, but more materials with low energy demand); total life cycle energy demand of these products is **4.190 Mill GJ/a** (or 36 GJ/t).

Therefore, the “additional energy needed if plastic products would be substituted up to a maximum" or the "energy saved by plastic products” is **1.020 Mill GJ/a** (or 33 GJ/t plastic product). This absolute figure can be expressed as a percentage in two ways:

- If the plastic products would be substituted up to a maximum, **32 %** more energy would be needed than in the total life cycle of these plastic products today.
- Plastic products enable to save **24 %** of the energy that would be needed, if plastic products were substituted up to a maximum.

For GHG emissions, given in CO_2 equivalents, the bold values above are:

- Life cycle GHG emissions of all substitutable plastic products: 140 Mt/a
- Life cycle GHG emissions of the products needed for substitution: 237 Mt/a
- Saving in GHG emissions: **97 Mt/a** (**69 %** more than emitted today or **41 %** less than in the case of substitution).

3) Comparison with the total market of plastic products

The total life cycle energy demand of all plastic products is 3.900 Mill GJ/a (102 GJ/t). If all substitutable plastic products were replaced, the additional energy needed would be 1.020 Mill GJ/a. The resulting “new market” (remaining plastics + substitutes) would have a life cycle energy demand of 4.920 Mill GJ/a. Expressed in percentages:

- **If plastic products would be substituted up to a maximum, 26 % more energy would be needed than in the total life cycle of *all* plastic products today.**
- Plastic products save 21 % of the energy that would be needed by a "new market", i.e. if all substitutable plastic products would be replaced by other materials.

For GHG emissions, the respective values are (given in CO_2 equivalents):

- Life cycle GHG emissions of all plastic products: 172 Mt/a
- Life cycle GHG emissions of the “new market”: 269 Mt/a
- Saving in GHG emissions: **97 Mt/a** (**56 %** more than emitted today in the life cycle of *all* plastic products or **36 %** less than in the case of a “new market”).

4) Effects in the total market of relevant products today

The share of plastic products on the total market of products, where plastics are used, is 18,3 % (3,4 % not substitutable and 14,9 % substitutable plastic products; see below). Products made of other materials are 81,7 % of this market or 170.000 kt/a.

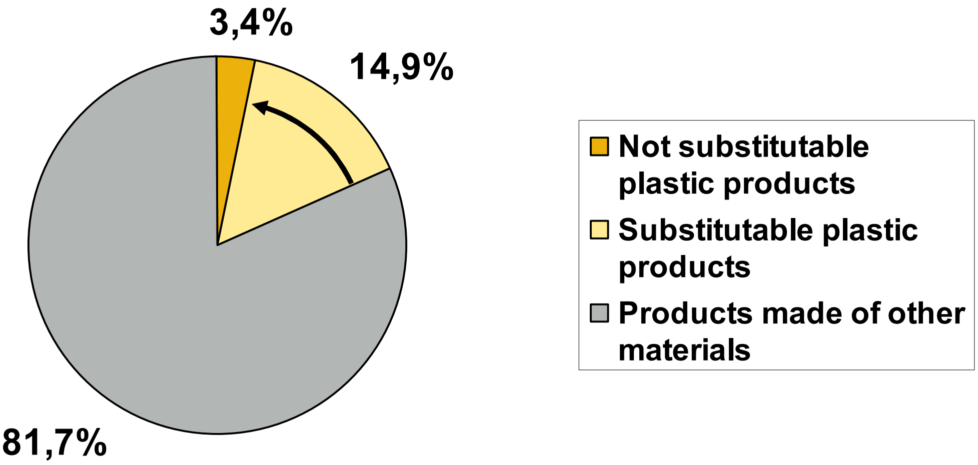

Figure 18: Share of substitutable and non substitutable plastic products on the total current market of products, where plastics are used.

The total life cycle energy demand of all plastic products is 3.900 Mill GJ/a (or 102 GJ/t). The total life cycle energy demand of all relevant products made of other materials, used on the market today, is 5.960 Mill GJ/a (or 35 GJ/t). Therefore, the total market of products, where plastics are used (plastics and other materials), consumes 9.860 Mill GJ/a. Still the “additional energy needed if plastic products would be substituted up to a maximum" or the "energy saved by plastic products” is 1.020 Mill GJ/a. Therefore, if plastics were substituted up to a maximum, the life cycle energy demand of the “new total market” of relevant products would be 10.880 Mill GJ/a. Expressed in percentages:

- If plastic products were substituted up to a maximum, **10,3 %** more energy would be needed than today in the total market of products, where plastics are used.
- Plastic products save **9,4 %** of the energy that would be needed by a "new total market" of relevant products, i.e. if all substitutable plastic products would be replaced by other materials.

For GHG emissions, the respective values are (given in CO_2 equivalents):

- Life cycle GHG emissions of the total market of products, where plastics are used (plastics and other materials): **507 Mt/a**.
- If plastic products were substituted up to a maximum, **19 %** more GHG would be emitted than in the total market of relevant products today, or **16 %** less GHG would be emitted than in the case of a “new total market”).

The "total market of products, where plastic products are used", and the share of plastic products on this market was estimated by using data on plastic shares from the following sources:

- Packaging: PlasticsEurope [2001b]
- Pipes: Estimation of TEPPFA: A plastics share of 60 % by metre, combined with an average mass ratio of 6,22 gives a plastics share of 19 % by mass.
- Other building applications: German market data on insulation show a plastics share of 24 %; German market data on flooring show a plastics share of 6 % (by mass), and European market data for windows show a plastics share of 38 %. The weighted average is 22,4 % as share of plastics in other building applications beside pipes, where plastic products are used.
- Electric and electronic sector: PlasticsEurope [2001]
- Automotive sector: PlasticsEurope [1999]
- Footwear: See market data presented in chapter 4.9.1.1.
- The share of plastic products within housewares, furniture and medicine was assumed. For the share of plastic products in other sectors the weighted average of the sectors listed above was used.

	Plastics market		Share of plastics in	Plastics	Alternative materials
Application sectors	**%**	**kt, 2002**	**total market**	**kt, 2002**	**kt, 2002**
Packaging	38,1%	14.525	17%	85.440	70.916
Building - Pipes	6,9%	2.637	19%	13.565	10.928
Building - Non Pipes	10,7%	4.072	25%	16.176	12.103
Electric/electronic	7,3%	2.783	22%	12.598	9.815
Automotive	7,0%	2.669	9%	28.695	26.026
Housewares	5,0%	1.906	50%	3.812	1.906
Furniture	4,0%	1.525	20%	7.625	6.100
Medicine	1,7%	648	50%	1.296	648
Footwear	1,1%	428	32%	1.339	910
Other	18,2%	6.929	18%	37.885	30.956
Total	**100,0%**	**38.123**	**18%**	**208.430**	**170.307**

Table 116: Estimation of the "total market of products, where plastic products are used", and the share of plastic products on this market.

5.6 Presentation of results “for the public”

In order to present the results in an understandable way by transformation of the results to other units, some examples are selected and described below. The main results of the study are: Throughout their total life cycle, plastics need 1.020 Mill GJ/a less energy than their possible substitutes and cause 97 Mt CO_2 equivalents less GHG emissions per year.

<u>Example “Oil tanker”:</u>

As reference tanker we took an ultra large crude carrier (ULCC) called “Jahre Viking”. This tanker with a length of 458 m can transport 137 Mill litres of crude oil [Kabel1 2004].

The 1.020 Mill GJ/a are equivalent to 22,4 Mill tonnes of crude oil. With a density of 0,86 kg/l we get 26.000 Mill litres or about 190 tankers like the “Jahre Viking” or a row of 87 km of ULCC tankers.

Ultra large crude tanker "Jahre Viking"	length	458	m
	capacity	137	Mill. litres crude oil
Conversion energy/crude oil			
Energy saved by using plastics	1.020	Mill. GJ/a	
Density crude oil	0,86	kg/l	
Kilogram crude oil	22.368.421.053		
Litre crude oil=	26.009.791.922		
Number of ultra large crude tankers=	190		
Length of all tankers=	86.952	m	

If we take a look at the period since plastics are on the market (the total amount of plastics consumed until today is approximately 25 times the mass of plastics consumed in 2002), then we get 4.750 ULCC tankers or a row of about 2.170 km.

Ultra large crude tanker "Jahre Viking"	length	458	m
	capacity	137	Mill. litres crude oil
Conversion energy/crude oil			
Energy saved by using plastics since plastics are one the market	25.500	Mill. GJ	
Density crude oil	0,86	kg/l	
Kilogram crude oil	559.210.526.316		
Litre crude oil	650.244.798.042		
Number of ultra large crude tankers	4.746		
Length of all tankers	2.173.811	m	

<u>Example “Heating and warm water”:</u>

In Germany 6.960 kWh/a [Die Verbraucher Initiative e.V. 2002] are used in a household per capita for heating and warm water. If we transform this consumption with 3,6 MJ = 1 kWh we will get 25.056 MJ per capita and year. Therefore, with the energy saved by plastic products

(1.020 Mill GJ/a), heating and warm water for about 41 Mill People could be made available. This is equivalent to the inhabitants of Spain or half of Germany.

6.960	kWh/capita.a in Germany
25.056	MJ/capita.a in Germany
1.020	Mill. GJ/a (Energy saved by using plastic products)
40.708.812	People

Example “GHG-Kyoto target (only CO_2 emission considered)”:

If the reduction target of the Kyoto protocol is only based on CO_2 emissions, it amounts to -318,6 Mill tonnes for the EU-15 for the period 2000/2012 [Institut der deutschen Wirtschaft Köln 2003]. So the emissions saved by plastic products (97 Mt/a CO_2-equivalent) are comparable to 30 % of the Kyoto reduction target for the EU-15 or approximately to the combined target of Italy + Spain or Italy + UK or Germany + The Netherlands.

Kyoto reduction target for CO2 [Institut der deutschen Wirtschaft Köln 2003]	Reduction commitment 2000/2012 [Mill. t]
EU-15	-318,6
UK	-41,6
Italy	-51,6
Spain	-47,2
Germany	-71,4
The Netherlands	-26,9

Example “GHG-Kyoto target (six gases approach - CO_2, N_2O, CH_4, HFC, PFC, SF_6)”:

If the reduction target of the Kyoto protocol is based on the six gas emissions (CO_2, N_2O, CH_4, HFC, PFC, SF_6), it amounts to -188,3 Mill tonnes for the EU-15 for the period 2000/2012 [Institut der deutschen Wirtschaft Köln 2003]. So the emission saved by plastic products (97 Mt/a CO_2-equivalent) are more than 50% of the EU-15 target or approximately the combined target of Italy + Spain or the EU-15 without Spain + Germany or the EU-15 without Italy + Germany.

Kyoto reduction target (six gases approach - CO2, N2O, CH4, HFC, PFC, SF6) [Institut der deutschen Wirtschaft Köln 2003]	Reduction commitment 2000/2012 [Mill. t]
EU-15	-188,3
Italy	-55,3
Spain	-56,6
Germany	-25,4

Example “CO_2 emissions from private cars”:

The emissions saved by plastic products (97 Mt/a CO_2-Equivalent) are comparable to 91 % of the CO_2 emissions from all private cars in Germany (~107 Mt CO_2) in the year 2000 [Shell Deutschland Oil 2004].

Example “Germans to Italian beach”:

The average performance of a private car in 2000 was about 11.800 km [Shell Deutschland Oil 2004]. If this distance is compared with the distance from Berlin to Rimini (Italy) and back, it turns out that Germans had to drive 4 – 5 times per year to the Italian beach and back to produce the same additional CO_2 emissions that would be caused by substitution of plastic products.

CO2 emissions of private cars in Germany (2000)	~ 107	Mill. tonnes
Private cars in Germany (2000)	~ 42,8	Mill. cars
Average performance/private car in Germany (2000)	~11.800	km/a
Distance: Berlin - Rimini (Italy) -Berlin	~2.400	km

6 SUMMARY AND CONCLUSIONS

The goal of this study was to estimate the savings of energy and greenhouse gas emissions achieved by the total market of plastic products (compared to theoretical substitutes) in Western Europe by means of a projection based on a sufficient number of examples.

First of all it was found that about 19 % of the total market of plastic products cannot be replaced realistically by other materials, meaning that in these cases a substitution of plastics is not possible without a decisive change in design or function or service rendered or in the process itself, which is delivering a certain service.

For the calculations carried out for this report, 75 % of all *substitutable* plastic products could be represented by 32 case studies. Within each case study, representing a certain product group, 1 – 6 different polymers and 1 – 7 different alternative materials were considered. Altogether 174 different products (case studies split into different materials) were included in a calculation model to quantify energy demand and GHG emissions within the total life cycle of the products.

Due to lack of data, identification and definition of further relevant case studies is currently not possible with reasonable expenditure. The possible effects of the remaining part of substitutable plastic products not covered by case studies were estimated in a conservative way: To extrapolate the results, only half of the *average* energy and greenhouse gas saving of the case studies investigated was used.

The results show that the total life-cycle energy needed to produce, use and recover plastic products in Western Europe is 3.900 Mill GJ/a and the total life-cycle GHG emissions are 172 Mt/a. Furthermore the results show that **substitution of plastic products up to a maximum** would need **600 – 1.400 Mill GJ/a more energy (or about 26 % more energy)** than needed in the total life-cycle of all plastic products today. In the same way, substitution of plastic products up to a maximum would cause **58 – 135 Mt or about 56 % more GHG emissions than the total life-cycle of all plastic products today**.

In other words, the plastic products on the market today have enabled savings of energy to an extent of 600 – 1.400 Mill GJ/a, equivalent to 22 Mill tonnes of crude oil carried by 190 ultra large crude oil tankers. The GHG emissions saved are equivalent to the total CO_2 emissions of Portugal (60 Mt in 2000) or Belgium (120 Mt in 2000) and are also equivalent to 30 % of the EU-15 Kyoto target regarding the reduction of GHG emissions

Only very few plastic products consume more energy than their possible substitutes made of different materials. Most plastic products need less energy to be produced, and additionally many plastic products save significant amounts of energy during the use phase (especially all automotive parts, insulation used in the sectors building and E&E, and packaging products). Generally the use phase is a very important part of the total life-cycle: On average 36 % of the total life-cycle energy demand of plastic products and 41 % of the total life-cycle energy demand of other materials are linked to the use phase. If products without effects in the use phase are excluded, then the use phase covers on average 50 % or 58 % of the total life-cycle energy of plastics and of alternative materials respectively.

The final conclusions based on these results are:

- Plastic products on the market today enable significant savings of energy and GHG emissions.
- This study has investigated the influence of different *materials* on the total life-cycle energy demand. In this respect the results show that in most cases plastic products help to use resources in the most efficient way.
- From the view of the total life cycle, plastics can therefore be considered as one of the most energy efficient materials.
- Substitution of plastic products by other materials will in most cases increase the consumption of energy and the emission of greenhouse gases.

Limitations of the conclusions given above:

This study only examined the consequences for energy demand and GHG emissions, when plastics as a *material* would be replaced by another *material*, while all other aspects of using these products (function, design, safety, etc.) should change as little as possible. Therefore this study did not investigate, how energy demand and GHG emissions change

- when plastic products are replaced not by “similar” products but by products which cause a decisive change in function, design or the processes itself
- when other aspects of processes than the material used are changed
- when new technologies can render a certain service without materials at all (e.g. wireless communication replacing processes that need cables).

When goods are packed and distributed, there are many influences on the energy demand beside the choice of packaging material. The use of one-way or reusable packaging changes logistic systems. Transport distances and the vehicle used (ship, plane, train, truck) have an enormous influence on energy consumption and GHG emissions.

In this study, PVC flooring was for example only replaced by linoleum. If PVC would also be substituted by carpets, wooden flooring or stoneware tiles, the effects on energy demand can be different than the results calculated in this study. Additionally the different mechanical and surface properties result in changes in using, cleaning and safety of the flooring material.

Cars for example became heavier to fulfil higher safety demands, resulting in higher fuel use. At the same time, more efficient engines have been developed and aerodynamic performance was improved, reducing fuel demand. Thirdly, mobility can be realised by cars as well as by other means of transport.

Also several plastic products have enabled new processes rather than substituted other materials: Plastic products have replaced many washing and cleaning processes in the medical sector. The development of electronic equipment would not have been possible without plastics. Silage films have partly substituted the labourintensive process of producing hay. Vegetable films enable higher yields on rather infertile land (reduction of humidity losses). Geomembranes prevent water losses in canals for irrigation.

For the general goal to use resources efficiently, all different possibilities to optimise a process have to be taken into consideration. Changes in the function and design of processes and services can have a bigger impact on the total energy demand than the effect of different materials.

Finally it has to be underlined that today a *comprehensive* comparison of products will not only be based on differences in energy consumption and GHG emissions, but will be a “sustainability assessment” that covers all relevant environmental, economic and social effects of the investigated products.

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