denkstatt

Product Sustainability

Executive Summary

The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe

Summary report

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Abbreviations

ABS	Acrylonitrile butadiene styrene
CO_2-eq	Carbon dioxide equivalents
E&E	Electric and electronic
ELV	End-of-life vehicles
EPS	Expanded polystyrene foam
EU	European Union
EU27+2	27 EU member states plus Norway and Switzerland
GHG	Greenhouse gases
GWP	Global Warming Potential
HDPE	High-density polyethylene
HIPS	High-impact polystyrene
LCA	Life cycle assessment / analysis
LDPE	Low-density polyethylene
LLDPE	Linear low-density polyethylene
MSWI	Municipal solid waste incinerator/incineration
PA	Polyamide
PE	Polyethylene
PET	Polyethylene terephthalate
PE-X	Cross-linked polyethylene
PLA	Polylactic acid
PMMA	Poly (methyl methacrylate)
PP	Polypropylene
PS	Polystyrene
PUR	Polyurethane
PVC	Polyvinyl chloride
SAN	Styrene acrylonitrile
U-value	Measure of thermal conductivity
WEEE	Waste electrical and electronic equipment
XPS	Extruded polystyrene foam

Number format 1.000,0: In this report numbers are written in the European (1.000,0) rather than the English (1,000.0) style, where the use of commas and full stops has opposite meanings. In this report the comma in numbers is used as separator for decimal digits and the full stop is used as the 1000 separator.

0 Foreword by PlasticsEurope - Statement of intent for initiating this study

Plastics generally have a poor or negative image in comparison with other materials, in particular with regard to their perceived impact on the environment and use of resources. The intention of this and earlier studies was to evaluate the actual impacts of typical exemplary plastic products across the whole life-cycle to demonstrate that the use of plastics can in many cases actually help save resources.

This study has a focus on energy use and climate change effects and assesses the whole life-cycle of the products in question.

While in several cases a plastics product may perform better than one made from other materials, it is not the intention to claim an overall material superiority. All materials have characteristics which make them more or less suitable for any given application. In many cases the most resource efficient solution may be a combination of different materials (e.g. aluminium coated plastic foil for some food packaging).

The preferred choice of material for any given application may also depend on other factors outside the scope of the study, such as the impact on littering or the impact within a well developed waste recovery system. The preferred solution in such cases is often country dependent and may be related to the proportion of single versus multiple use applications.

The examples of plastic applications investigated in detail in the study are all based on plastics derived from fossil fuels. While plastics from renewable resources are now being developed, their current market penetration is not high enough to have a significant effect on the overall results or conclusions.

Nevertheless, it is worth mentioning the possible future important role of renewable resources in the plastics industry. There are two categories of plastics possible from renewables. One option is the production of monomers to make new polymers such as PLA. Here the commercial challenge is to compete with existing large volume plastics in terms of production economics and adapting processing equipment. The other route is to make high volume monomers such as ethylene (or other ethylene derivatives) from ethanol derived from renewable sources. These can then be used in existing polymerisation plants making the well known polyethylene grade ranges. In both cases the chemistry is proven, but a key consideration will be the amount of (non-renewable) energy used in the overall manufacturing chain.

The scope of the study, covering all plastics applications across Europe, is so extensive that a large number of assumptions and extrapolations have had to be made. Nevertheless we would trust the general overall conclusions are sufficiently valid – as also confirmed in the accompanying critical review process - to convince policy makers that the use of even current fossil fuel based plastics do indeed make a significant positive contribution to the goals of energy efficiency and climate protection.

It is hoped that with this study policy makers will recognize there should be no automatic preference for “renewable” raw materials, but rather the concept of “life-cycle thinking” should be adopted when assessing policy options.

It should be noted that the examples of plastics applications evaluated do not imply a preference for certain plastics over others. The availability of information from various sources was the key, but the study does in fact include examples of most of the large volume plastics.

1 Introduction

In order to produce plastic products, energy resources are consumed. Currently such energy resources are almost entirely obtained from non-renewable sources and by using them, greenhouse gas (GHG) emissions are produced. Nevertheless, even more energy would be consumed and more GHG emissions emitted, if plastic products were to be substituted by alternative materials. This was established in a study undertaken by GUA/denkstatt in 2004/2005 [Pilz et al., 2005].

In addition, some plastic products enable energy savings to be made during their life-cycle, even without being compared with other materials. Examples are insulation materials (valid in fact for all insulation materials), wind-power rotor blades, plastic packaging materials that reduce food losses or help avoid damage to durable goods (valid to some extent for other packaging materials), new products substituting heavier plastic products, and products that incorporate improvements by ongoing innovation, concept changes and dematerialisation.

The study "The impact of plastics on life cycle energy consumption and GHG emissions in Europe" consists of two parts:

Part 1 is an update of the comprehensive GUA/denkstatt study mentioned above, where the total market of (substitutable) plastic products in Europe is represented by 32 case studies, and where plastics are compared to the ***mix*** of alternative materials available on the market with regards to energy consumption and GHG emissions in the total life cycle of products.

Part 2 presents further arguments on the beneficial aspects of plastics in terms of enhancing energy efficiency and climate protection, both now and in the future. Part 2 addresses the most important public and political concerns and prejudices related to plastics and their impact on energy use and climate change. It hopefully "puts things into perspective".

PlasticsEurope and denkstatt agreed to take the "80/20 approach" for the study. This means covering 80 % of the results with 20 % of the effort required for a more comprehensive study. The following summarises the main assumptions and implications of this approach:

- The study is limited to the estimation of energy demand and greenhouse gas emissions on account of their current high priority in EU policies.
- The results provide an indication of the status and trends of application sectors rather than details on specific products.
- The study is not a detailed LCA comparison between plastics and alternative materials in *single* applications, but rather provides a realistic estimate of the overall impact of the total market of plastic products (including the uncertainties of such an estimation).
- The study aims to put things into perspective, by identifying both important and negligible influences in the energy and GHG balance across the total life-cycle.

Both parts of the study have been critically reviewed by Adisa Azapagic, Professor of Sustainable Chemical Engineering at the School of Chemical Engineering and Analytical Science, University of Manchester, United Kingdom and Roland Hischier, member of the Technology & Society Laboratory at EMPA, the Swiss Federal Laboratories for Materials Testing & Research in Sankt Gallen, Switzerland (The Critical Review Reports are appended to this summary).

2 Summary of PART 1: The impact of plastics on life cycle energy consumption and greenhouse gas emissions in Europe – Effects of a theoretical substitution of plastics

2.1 Goal and approach

The goal of the first part of the study is to update the comprehensive GUA/denkstatt-study of 2004/2005 (“The contribution of plastic products to resource efficiency”), where the total market of (theoretically substitutable) plastic products was covered by 32 case studies, with a polymer split reflecting the total market [Pilz et al., 2005]. In a detailed calculation model the study quantified the effects on energy consumption and GHG emissions, in the event that plastic products were to be substituted by other materials. These were various established materials which could realistically substitute the plastic. In such a way the overall savings in both energy consumption and GHG emissions, as a result of all plastic products in Europe was calculated.

The update expanded the geographical scope from EU15+2 to EU27+2 (including Norway plus Switzerland), integrated new data on volumes in application sectors, and updated numerous mass, energy and GHG emission data in the life-cycle phases of the products.

Nevertheless the study generally follows an “80/20-approach”, meaning that the authors aim to cover 80 % of influences with 20 % of effort that would be required for a more comprehensive study. As a result a high degree of reliability was ensured for the general magnitude of the overall results, but not for every specific figure in the case studies investigated, where – based on the “80/20-approach” – many (reasonable) assumptions had to be made where data were not easily available.

2.2 Basic data

According to Plastics Europe 52.500.000 tonnes of plastic polymers/resins were consumed by converters in the EU27+2 in the year 2007 [PlasticsEurope, 2008]. These 52,5 Mt include "plastic products/applications" and "non-plastics applications", the latter being polymers and thermosets used for fibres, coatings, adhesives, sealants, etc. (fibres not included in 52,5 Mt). This study is based on "plastic products", excluding fibres, coatings, adhesives, sealants, as these are not recognised as "plastic products" by the public, politicians or in the analysis of waste. In addition, plastic products made of thermosets other than PUR (less than 10 % of all plastic products) are not included in this study, as sufficient data on their distribution across the main application sectors is not available. Taking these considerations into account leads to a converter demand of 46.430.000 tonnes of plastics in Europe (EU27+2) in the year 2007 [PEMRG, 2009], which forms the basis for further calculations.

For the calculations made for this report, case studies were only considered for sectors where plastics are substitutable. It was found that about 16 % of the total market of plastic products cannot be realistically replaced by other materials, meaning that in these cases a substitution of plastics is not possible without a significant change in design, function, service rendered or in the process itself, which delivers a certain service.

A total of 173 different products were analysed, Within each case study, representing a certain product group, up to 6 different polymers and up to 7 different alternative competing materials were considered (see Appendix, Table 3 and Table 4)

Overall, about 75 % of substitutable plastic products are covered by the case studies of this report. Table 1 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.

	Total Market		Coverage			Coverage		
	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	19.180	41,3%	2%	0%	98%	0,9%	0,0%	40,5%
Building - Pipes	2.830	6,1%	0%	0%	100%	0,0%	0,0%	6,1%
Building - Non Pipes	7.050	15,2%	0%	53%	47%	0,0%	8,1%	7,1%
Electric/electronic	2.590	5,6%	56%	27%	18%	3,1%	1,5%	1,0%
Automotive	3.700	8,0%	55%	0%	45%	4,3%	0,0%	3,6%
Housewares	1.840	4,0%	0%	50%	50%	0,0%	2,0%	2,0%
Furniture	1.470	3,2%	0%	50%	50%	0,0%	1,6%	1,6%
Medical applications	630	1,3%	50%	30%	20%	0,7%	0,4%	0,3%
Footwear	410	0,9%	0%	56%	44%	0,0%	0,5%	0,4%
Other sectors	6.700	14,4%	50%	50%	0%	7,2%	7,2%	0,0%
Total Market	**46.400**	**100%**				**16,2%**	**21,2%**	**62,5%**

Table 1: Non substitutable segments of the market of plastic products; coverage of substitutable plastics by case studies (Market volume is based on the year 2007 [PEMRG, 2009]).

Calculation of life-cycle energy and GHG emission balances:

Data for the production phase of plastic products were mostly taken from the “Ecoprofiles” as published by PlasticsEurope. Production data of alternative materials was taken from the database of Ecoinvent [2007] or comparable sources.

In the use phase the calculation covers issues where plastic products have a different impact on energy and GHG emissions compared to alternative products. The effects considered are mainly fuel consumption for transportation, prevented food losses, differences in thermal insulation properties, and fuel savings due to the lower mass of plastic automotive parts.[1]

Waste management conditions were based on data from 2007. Details of data used for the substitution model and for waste management are shown in the Appendix (Table 5 and Table 6) of this summary.

[1] For savings of energy and GHG emissions by plastic insulation used in the building sector see part 2 of this study (not included in part 1 as other materials will normally enable similar savings).

2.3 Results

The results demonstrate that both energy consumption and greenhouse gas (GHG) emissions would increase significantly, if plastic products were to be substituted to a theoretical maximum by other materials.

In other words plastic products, having substituted more traditional materials are helping save energy and reducing greenhouse gas (GHG) emissions.

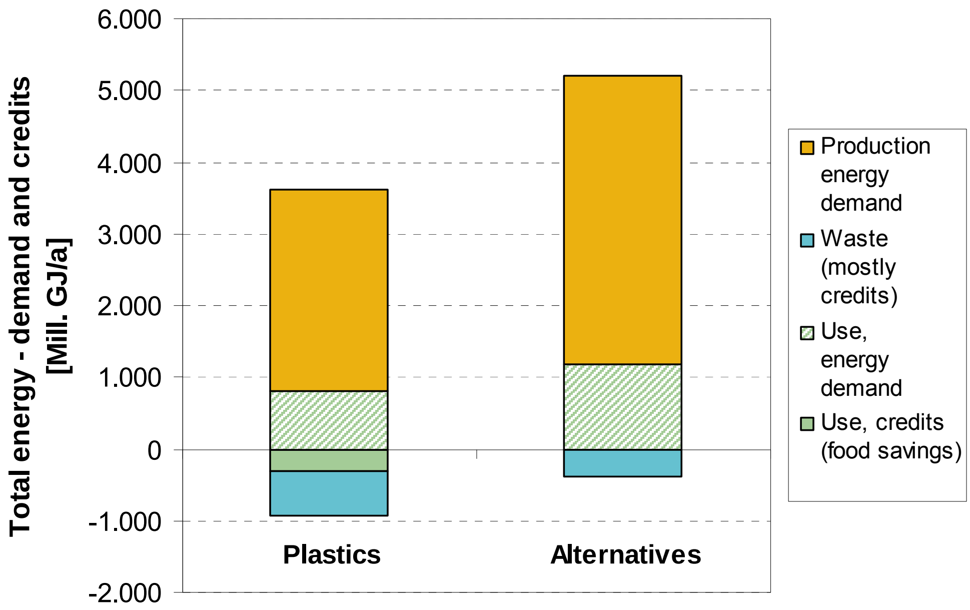

Figure 1: Life-cycle energy consumption of plastic products (investigated case studies; 63 % of total market covered) and their potential substitutes, split into life-cycle phases production, use and waste management. Positive values stand for energy consumption, negative values indicate energy credits for prevented food losses, saved primary production (by recycling) and saved production of electricity and heat (by energy recovery).

For example, **substituting plastics in the case studies** throughout Europe (EU27+2) in 2007 would increase the **life-cycle energy consumption** by around **2.140 million GJ per year** and the **GHG emissions** would increase by **110 Mt CO_2-equivalents per year**.

The energy savings that can be attributed to the use of plastics varies significantly according to the application area, with packaging being by far the most important. A conservative **estimate of the impact of the total plastics market has been made by extrapolation** using only half of the energy savings and GHG emission reductions of the quoted examples.

The results show that the total life-cycle energy needed to produce, use and recover plastic products in Europe (EU27+2) is 4.300 million GJ/a and the total life-cycle GHG emissions are 200 Mt/a.[2] Furthermore it can be

[2] Note that these figures also include energy consumption and GHG emissions in the use phase of products, e.g. mass related fuel demand of automotive parts.

concluded that **substitution of plastic products by other materials wherever possible would need around 57 % (1.500 – 3.300 million GJ/a) more energy** than currently used in the total life-cycle of all plastic products today. In the same way, substitution of plastic products up to the theoretical maximum would cause **78 – 170 Mt or about 61 % more GHG emissions than the total life-cycle of all plastic products today** (see also Figure 2).

In other words, the **plastic products on the market today have enabled energy savings of 2.400 million GJ per year**, equivalent to 53 million tonnes of crude oil carried by 205 very large crude oil tankers. The **GHG emissions saved (124 Mt per year)** are equivalent to the total CO_2 emissions of Belgium in the year 2000 [UNFCCC, 2009] and are also equivalent to 39 % of the EU15 Kyoto target regarding the reduction of GHG emissions.

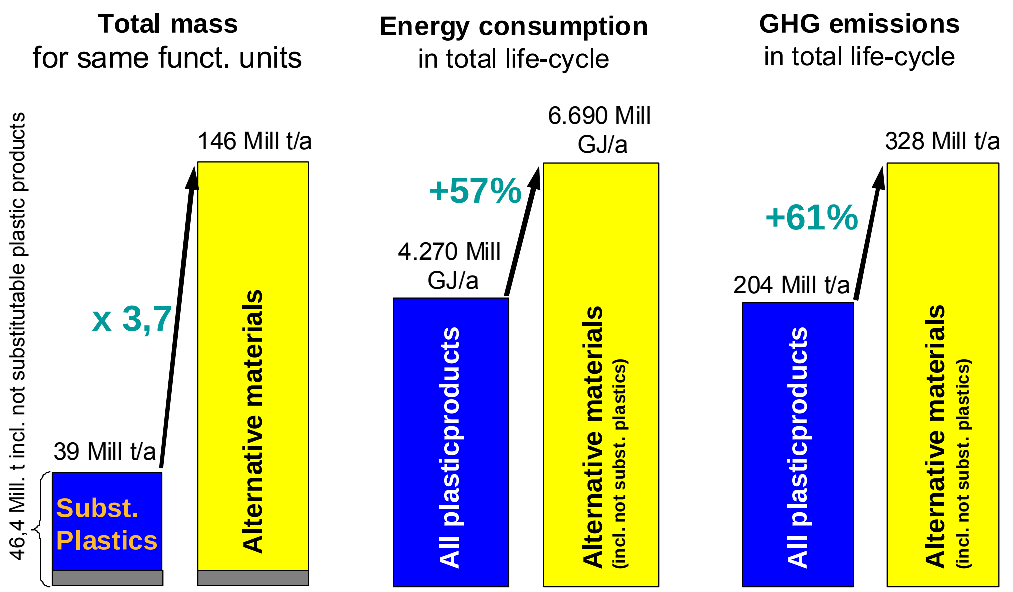

Figure 2: Changes in product mass, energy consumption and GHG emissions, if plastic products would theoretically be substituted by alternative materials.

Energy savings (+) and additional energy demand (–) of plastic products compared to alternative materials, split into contributions of the main application sectors and the life-cycle phases production, use and waste management are presented in the Appendix, Figure 4.

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 than their alternatives, and additionally many plastic products save significant amounts of energy during the use phase .This is especially the case for automotive parts, insulation used in the building[3] and E&E sectors, and packaging applications. Generally the use phase is an important part of the total life-cycle: on average 18 % of the total life-cycle energy demand of plastic products and 24 % of the total life-cycle energy demand of other materials are linked to the use phase. If products

[3] For savings of energy and GHG emissions by plastic insulation used in the building sector see part 2 of this study (not included in part 1 as other materials will normally enable similar savings).

without effects in the use phase are excluded, then the use phase covers on average 31 % of the total life-cycle energy of plastics and of alternative materials.

During the various calculations, modifications, updates and sensitivity analyses performed in this study it was found that the relatively large number of case studies investigated makes the overall results quite stable. This is because variations in one case study become small in relation to the total market, and possible improvement of data shows a random distribution between plastics and alternative materials. Additionally, many assumptions were deliberately conservative, meaning that the subsequent results are biased in favour of the alternative, competing materials.

3 Summary of PART 2: Additional arguments on the benefits of plastics in relation to energy efficiency and climate protection

3.1 Goal and approach

The goal of the second part of the study was to provide further evidence of the benefits of plastics in relation to energy efficiency and climate protection. This includes improvement of plastics performance over time (increased material and production efficiency), the benefits of increased plastic insulation, examples of other plastic products with more use-benefits than production impacts, and benefits and efficiencies of different waste strategies. In addition issues such as renewable resources for plastics, the relevance of plastics in the consumer carbon footprint, prevention of food losses, and contributions of plastics to innovation and dematerialisation are discussed.

For this purpose information on trends, ranges, and orders of magnitude are summarised in order to address the most important public and political perceptions and prejudices related to plastics and their connection with energy and climate change. Such information will be useful in discussions and help "put things into perspective".

All of this is finally summarised in a so-called "carbon balance" of plastic products, whereby production emissions are compared with the benefits in use for both the current situation as well as an estimated outlook for 2020.

3.2 Exemplary facts and figures

3.2.1 Improvement of plastic production and products over time

Recent data for six typical packaging products and for window profiles were compared with historical data in order to assess the improvements achieved over time. Reductions in the mass per functional unit and the production energy and associated GHG emissions were assessed.

The packaging products included containers for milkshakes, for cream, a condensed milk portion pack, a liquid washing agent bottle, a jam catering pack, and a still mineral water bottle.

The time series of different plastic packaging materials show the energy and GHG emission savings due to a mass reduction of the functional unit of up to 28 % since 1991. The improvement of production processes to produce the plastic packaging (at 5 % maximum) is significantly lower than for mass reduction and in some cases values are even slightly negative (see Appendix, Table 7).

In the development of window frames over time, the improved insulation properties are the dominating factor: Energy loss through the frame today is only 1/3 of the value achieved in 1970. The annual effect of improvements in efficiency concerning energy consumption and GHG emission of window frames during the last 30 years is 7 times (energy) and 9 times

(GHG emissions) higher than the yearly requirements for the production of these window frames.

3.2.2 Benefits of increased (plastic) insulation

In Part 1 of this study, plastic insulation materials were compared to mineral wool and glass foam, with the result that on average plastic insulation materials consume 16 % less energy and produce 9 % less GHG emissions than the alternative mix of mineral wool and glass foam (total life-cycle, effect of blowing agents included, use effect of saving heating & cooling energy excluded because identical in the defined functional units). However, energy and GHG considerations are not the only criterions for choice of material in specific insulation applications. Sustainability analysis consisting of environmental, economic and social impact is also necessary.

The significant energy savings enabled by all insulation materials in the use phase are the most important energy effect in their lifespan, with the production energy typically accounting for less than 1 % of the total life cycle energy.

The results of a study conducted by denkstatt [Pilz & Mátra, 2006] showed that plastics insulation materials enable enormous energy savings during their service life; with the energy needed for production being balanced by energy savings within the first 4 month of the use-phase.

In fact across their total life cycle, plastics insulation boards save 150 times more energy than is needed for their production.

An estimation of the total net energy savings as a result of all plastics insulation applied to improve insulation conditions in the building sector in 2004, gives a net energy saving of 9.500 – 19.900 million GJ over their total life-time and will avoid the emission of 536 – 1.120 million tonnes of CO_2-equivalents.

3.2.3 Use benefits of plastic products in the generation of renewable energy

Plastics play an increasing role in the generation of renewable energy. Examples are the plastic rotor blade of a wind turbine and thin film photovoltaic units, where non-silicon semiconductors (metal or organic) are printed on plastic films.

Wind power turbines: GHG emissions savings within the use phase (wind power replacing European electricity mix) are 140 times higher than the emissions for production, in the event that one third[4] of the GHG savings enabled by the wind power plant are allocated to the rotor (see Appendix, Figure 5).

Photovoltaic panels: GHG emission savings during the use phase (solar energy replacing European electricity mix) are 340 times higher than the emissions for production, when one fourth[5] of the GHG savings enabled by the photovoltaic panel are allocated to the plastic film (see Appendix, Figure 5).

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[4] due to three main functional components of a windmill

[5] due to four main functional components of a photovoltaic unit

3.2.4 The effects of renewable resources on energy and GHG emissions

There are two possible categories of plastics that can be derived from renewable resources. One option is the production of new monomers (such as polylactic acid) to make new, possibly biodegradable, polymers (e.g. PLA). Here the commercial challenge is to compete with existing large volume plastics in terms of production economics and adapting processing equipment. The other route is to make high volume monomers such as ethylene (or other ethylene derivatives) from ethanol derived from renewable sources. This can then be used in existing polymerisation plants making the well known polyethylene grade ranges. In both cases the chemistry is proven, but a key consideration will be the amount of non-renewable energy used in the overall manufacturing chain.

Plastics made of biodegradable polymers derived from renewable sources

The example of packaging made of PLA versus PET shows the influence of production conditions (esp. energy mix) of PLA products and even more so the influence of waste management options on the results of life-cycle GHG emissions, if conventional plastics (PET) and bioplastics (PLA) are compared. Under current waste management conditions bottles made from PET have less impact on global warming than bottles made from PLA. When plastic bottles are diverted from landfill, the result can be reversed. Depending on the waste management conditions applied the range between minimum and maximum CO_2-equivalent emissions is quite high (see Appendix, Table 8).

Plastics made from ethanol derived from renewable sources

To estimate the greenhouse gas emissions (in CO_2-equivalents) associated with the production of LDPE film based on ethylene derived from renewable resources as a base for further processing into bioplastics, three recently published studies [DfT, 2008], [Zah et al., 2007] & [Baitz et al., 2007] were considered and compared to LDPE film based on fossil fuels [Boustead, 2005].

The GWPs of all case studies examined are within a broad and similar range (see Appendix, Figure 6). For LDPE from renewable resources the broad range is a result of the choice of the resource (use of corn, wheat, sugar beet, sugar cane, etc.) and also of the type of waste treatment applied. In the case of LDPE based on fossil resources the range is a consequence of different waste management options.

On average PE film based on renewable resources shows an advantage of 2 to 3 kg CO_2 per kg PE compared to PE film derived from fossil resources. This benefit can however vary considerably depending on the resources used to produce the bio-based ethanol.

3.2.5 The benefits of recycling and recovery in relation to energy and GHG emission reductions

Today plastic waste should always be considered as a valuable secondary resource that can be used to save energy and prevent GHG emissions. An overview on the benefits of recycling and recovery for energy and GHG emissions is given with the example of LDPE using the most important recycling and recovery processes namely mechanical (material) recycling of “pure” PE polymer waste fractions, feedstock recycling, industrial energy recovery, and municipal solid waste incineration.

All recycling and recovery options result in net-savings of energy resources (see Appendix, Figure 7). GHG emissions are also reduced by material and feedstock recycling and by energy recovery with high energy efficiency (see Appendix, Figure 8). Energy recovery of plastic waste in MSWI plants at current European conditions produces more CO_2 emissions than it prevents due to substituted electricity and district heat production.

Figure 7 also shows that the benefits of material recycling can become comparable or even lower than the benefits of feedstock recycling or industrial energy recovery, in cases where material recycling produces high material losses or where the mass of substituted virgin material is considerably lower than the recycled plastic mass.

In the future it will be important to divert plastic waste from landfills, to utilise plastic waste as a valuable secondary resource in various recovery and recycling processes. The energy efficiency of MSWI plants should also be improved wherever possible.

3.2.6 Waste recovery strategies compared: ”Full compliance with product related EU directives” versus “maximum diversion from landfill”

The effects on energy and GHG emissions of two different recovery strategies are compared:

1: Full compliance with EU directives on packaging waste, WEEE and ELV: today with full compliance; compare with effects of

2: Divert all domestic and commercial waste from landfills / landfill ban

Estimates are generated for

- plastic waste involved
- all materials involved

For plastic and paper in mixed waste streams, two scenarios are considered:

- Scenario A: total mass to MSWI
- Scenario B: 50 % of plastic and paper waste to industrial energy recovery and feedstock recycling, rest to MSWI

The results of this rough estimation show that the energy consumption and GHG emissions prevented by a “diversion from landfill” strategy are (depending on the scenario) up to 11 times (energy) and up to 28 times (GHG) higher than the energy consumption and GHG emissions avoided by an assumed full compliance with the EU directives on packaging, ELV and WEEE (see Appendix, Figure 9).

The results also show that it is important to extract high calorific mixed plastic waste fractions from mixed residual waste for utilisation in industrial energy recovery or feedstock recycling processes.

3.2.7 Relevance of plastic products in relation to the total consumer carbon footprint

To calculate the relative share of the carbon footprint of plastic products within the total consumer carbon footprint, an estimated figure for the total consumer carbon footprint has been derived from Hertwich & Peters [2009], where the average consumer carbon footprint for the EU27+2 is given as 12,2 tonnes CO_2-equivalents per capita in 2001. We assume that this value has increased by at least 2 % per year until 2007, which gives 13,7 tonnes CO_2-equivalents per capita in 2007.

Part 1 of this study explains that in 2007 510 million people consumed 46,4 Mt of plastic products in 2007, i.e. 91 kg/capita. The results of Part 1 show that average production emissions together with the average net emissions from the waste management phase are 3,4 kg CO_2-equivalents per kg plastics, and GHG benefits of the use-phase are -1,5 kg CO_2-equivalents/kg plastics, giving a total life-cycle balance of 1,9 kg CO_2-equivalents/kg plastics or 173 kg CO_2-equivalents per consumer. This equates to 1,3 % of the total consumer carbon footprint of 13,7 tonnes CO_2-equivalents per capita as shown below (see Figure 3).

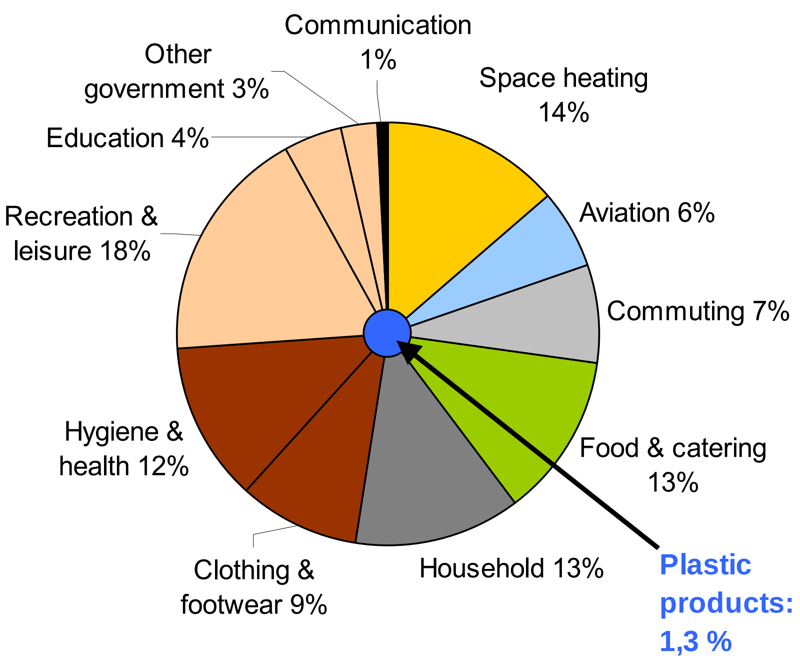

Figure 3: Relevance of plastic products in the total carbon footprint of consumers. Split of carbon footprint into sectors from www.carbontrust.co.uk [Carbon Trust, 2009]; calculation of relative share of plastic products based on data of this study.

3.3 Rough estimations and semi-quantitative arguments

3.3.1 Effects of prevented food losses on energy and GHG emissions

A rough estimation of the possible magnitude of CO_2 savings resulting from prevented food losses enabled by plastic packaging for fresh food shows that the CO_2 benefit of 10–20 % prevented food losses is 4-9 times higher than the CO_2 emissions of packaging production (see Appendix, Table 9). Such use effects therefore have significantly more influence concerning GHG emissions than the packaging production (for those packaging applications where food losses occur and are avoidable).

If we assume that 70 % of all food packaging (plastics and other materials) prevent the loss of 20 % of the food packed (compared to distribution of goods *without* packaging), and if we assume the same CO_2-ratio for packaging production and food production as in the examples given above, then the respective CO_2 benefit for plastic food packaging can be estimated at 190 Mt of CO_2 emissions.

In addition, 22 Mt of CO_2 emissions are avoided, if plastic packaging used to pack fresh food as listed above prevents 10 % more food losses compared to the theoretical situation that this fresh food would be packed in alternative packaging materials (according to Part 1 of this study).

3.3.2 Benefits in relation to energy and GHG emission reductions enabled by innovation, concept changes and dematerialisation

To obtain a rough impression what influence application changes have on energy consumption and Global Warming Potential, two case studies have been approximately assessed:

(i) to listen to music stored on CDs versus MP3 files

(ii) to make images with an analogue versus a digital camera.

The results are as follows:

Energy consumption and GHG emissions decrease by a factor 60 – 106 when using MP3-players instead of portable CD-players

Energy consumption and GHG emissions decrease by a factor 26 – 107 when using digital cameras (with SD cards) instead of analogue cameras (with film cartridges).

3.3.3 The estimated "Carbon balance" for the total market of plastic products in 2007 and a forecast for 2020

The "carbon balance" is here defined as the "amount of greenhouse gases prevented" (as a result of the use- and recovery-benefits of plastics) divided by the amount of greenhouse gases emitted during the production of plastics" (both figures expressed in CO_2-equivalents).

Such a carbon balance has been established for the total market of plastic products consumed in the EU 27+2 in the year 2007, representing the current situation. In addition, a forecast of the carbon balance in 2020 is given, based on estimated developments in the various application sectors (see Table 2).

It should be noted that the list of examples for use benefits in the carbon balance is not complete, but rather shows relevant applications where the benefits have so far been quantified.

In 2007 the estimated use benefits were 5-9 times higher than the emissions from the production and recovery phases.

In 2020 the estimated use-benefits could be 9-15 times higher than the forecast emissions from production and waste management at that time. This means that the use benefits of plastic products outweigh by far their production emissions, when the carbon balance is established for the market of plastic products as a whole. The contribution to such benefits in the use phase is of course different for different applications.

The potential of plastics to contribute to reduced GHG emissions will even increase in the future. The main drivers for the increasing use-benefits as listed in the carbon balance above, will be the politically established targets to reduce energy consumption and GHG emissions in the building and the automotive sectors, etc. and to increase the share of renewable energy production, as established in the EU action plan on energy and climate change up to 2020. But in addition the use of plastics to preserve packed goods (especially food) and to substitute less energy/GHG-efficient materials will enable plastics to provide an important contribution in reducing GHG emissions across Europe.

"Carbon balance" of EU27+2 plastics market	2007	2020	Av. changes until 2020
	Mt CO2-equ.	Mt CO2-equ.	Mt CO2-equ.
Production	**160**	**180**	
production increase (2% p.a.)			47
increased material efficiency			-21
20% PE from renewable resources?			-6
Effects of recycling/recovery/disposal	**-1**	**-6 to +18**	-5 to +19
Exemplary use effects:			
substitution of less efficient materials	**-46 to -85**	**-59 to -110**	-19
fuel savings	**-17**	**-34**	-17
insulation	**-540 to -1.100**	**-1.200 to -1.800**	-700
prevented food losses	**-100 to -200**	**-150 to -300**	-75
wind power rotors & solar panels	**-60**	**-250 to -500**	-310
Total carbon balance	**-600 to -1.300**	**-1.500 to -2.500**	
Ratio (Use+Recovery) vs. Production	**-5 to -9**	**-9 to -15**	

Table 2: "Carbon balance" of the total market of plastic products in the EU27+2 for 2007 and for 2020 (estimated extrapolation) showing the GHG emissions of the production and end-of-life-phase as well as exemplary estimated ranges of use benefits (negative values) enabled by plastic products. The last line gives the ratio of GHG-credits from the use phase (and recovery phase) divided by the GHG emissions from the production phase.

4 Conclusions

The key messages based on these results are:

- Plastic products used on the market today enable significant savings of energy and GHG emissions (the production and use phase are most important for 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 where plastics are used today, they help to use resources in a very energy efficient way (i.e. plastics enable resource efficient solutions).
- Substitution of plastic products by other materials will in most cases increase the consumption of energy and the emission of greenhouse gases.
- From the view of the total life cycle, plastics can therefore be considered as one of the most energy efficient materials.
- Plastics often facilitate reduced material consumption.
- The use of plastics for thermal insulation, for food packaging or to produce renewable energy results in extraordinary “use”-benefits.
- Polymers based on renewable resources are not per se better than conventional plastics based on fossil resources. The range of their GHG balance (due to feedstock selection and waste options) is much greater than the difference with conventional polymers
- Plastics from renewable resources could contribute to reduction of GHG emissions in the future, if the renewable sources as well as the waste management applied are chosen advantageous.
- A “carbon balance” of the total plastics market in the EU27+2 shows that the estimated use phase benefits (reduction of GHG emissions enabled by plastic products) were roughly 5 - 9 times higher than the emissions from production and recovery of all plastics in 2007. *It should be noted that the list of examples for use benefits in the carbon balance is not complete but rather shows relevant applications where the benefits have been quantified so far.*
- The potential for increasing use benefits up to 2020 is much higher than the additional emissions from the growth of plastics. In 2020 the estimated use-benefits could be 9-15 times higher than the emissions from production and waste management in 2020.
- The main drivers for the increasing use-benefits as described in the carbon balance above will be targets to reduce energy consumption and GHG emissions in the building sector and automotive sectors, etc. and targets to increase the share of renewable energy production, as given in the EU action plan on energy and climate change up to 2020. But the use of plastics to preserve packed goods (especially food) and to substitute less energy/GHG-efficient materials will also provide important contributions to the reduction of GHG emissions throughout Europe.

Limitations of the conclusions given above:

Part 1 of 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 to what extent energy demand and GHG emissions could change in the following circumstances:

- when plastic products are replaced not by "similar" products but by products which cause a decisive change in function, design or the processes themselves
- 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).

In Part 2, only the performance (improvement) of plastics is considered and, appropriately, no attempt at comparison with other materials has been made. It should be borne in mind that, similar to plastic products, products made from alternative materials will also change (improve) over time and in some cases could also have similar beneficial effects (e.g. benefits of insulation are not so material-dependent) so that no direct comparison between plastics and other materials is possible or appropriate.

For the general goal of using 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 a fully *comprehensive* comparison of products should not only be based on differences in energy consumption and GHG emissions, but should involve a full "sustainability assessment" that covers all relevant environmental, economic and social effects of the investigated products.

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6 APPENDIX A: Selected important tables and figures

Table 3 gives an overview of the 32 case studies identified and 173 different products analysed (case studies split into different materials) in this report. These different products were included in a calculation model to quantify energy demand and GHG emissions within the total life cycle of the products. Polymers and alternative, competing materials considered are shown in Table 4.

	Number of case studies	Number of analysed products	Case study titles (analysed product groups)
Packaging	7	57	small packaging; beverage bottles; other bottles; other rigid packaging; shrink and stretch films; carrier-bags; other flexible packaging
Building except pipes	3	11	insulation; flooring; windows
Pipes	9	55	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
Medical applications	2	4	syringe; infusion container
Footwear	1	4	soles
Total	**32**	**173**	

Table 3: Case studies analysed in this report.

	Polymers covered by case studies	Alternative materials covered by case studies
Packaging	LDPE; LLDPE; 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
Medical applications	PP; PVC	Glass
Footwear	PVC; PUR	Leather; Rubber

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

Figure 4 presents the difference between plastic products and alternative materials regarding energy demand for all case studies analysed aggregated to main application sectors in million GJ/a in The EU27+2. The results are split into the life-cycle phases production, use and waste management.

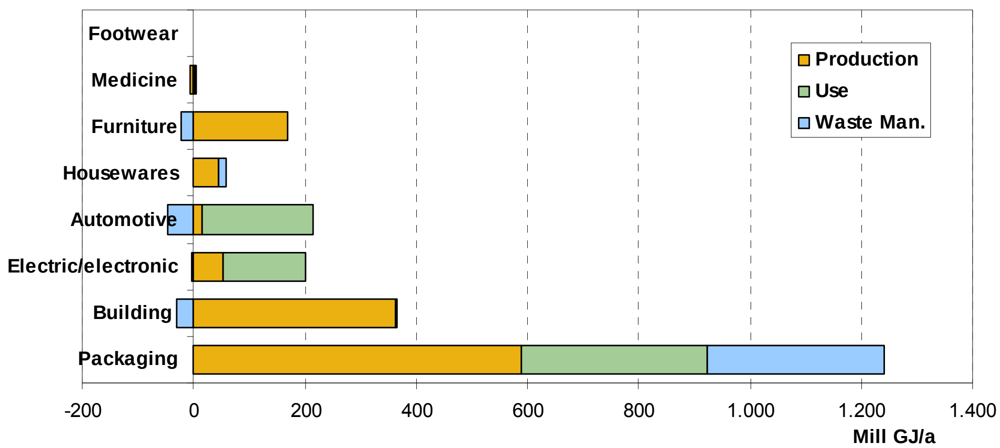

Figure 4: Energy savings (+) and additional energy demand (–) of plastic products compared to alternative materials, split into contributions of the main application sectors and the life-cycle phases production, use and waste management (use effect of insulation excluded because identical in the defined functional units).

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	3,18%	1,00	0,02	0,41	0,36	0,04	0,11		0,06				
beverage bottles	4,98%	0,83							0,83				
other bottles	2,53%	1,00	0,03	0,70	0,14	0,01			0,12				
other rigid packaging	13,15%	1,00		0,41	0,32	0,00	0,21	0,06					
shrink and stretch films	4,48%	1,00	1,00										
carrier-bags	1,37%	1,00	1,00										
other flexible packaging	10,79%	1,00	0,72		0,22	0,03	0,03						
big drain & sewer pipes	1,64%	1,00		0,19	0,12	0,69							
small drain & sewer pipes	1,64%	1,00		0,19	0,12	0,69							
big drinking water pipes	0,53%	1,00		0,71		0,29							
small drinking water pipes	0,53%	1,00		0,71		0,29							
agricultural pipes	0,10%	1,00				1,00							
conduit pipes	0,70%	1,00		0,57		0,43							
gas pipes	0,32%	1,00		1,00									
heating & plumbing pipes	0,39%	1,00			0,28	0,06				0,67			
industry pipes	0,24%	1,00		0,50	0,06	0,29				0,03	0,12		
Insulation	3,72%	1,00					0,13	0,48				0,40	
Floor coverings	0,96%	3,00				3,00	(XPS)						
Windows	2,45%	2,04				2,04							
housing	0,81%	1,00			0,25		0,27				0,47		
insulation in refrigerators	0,18%	1,00					(HIPS)					1,00	
Under the hood	1,55%	1,00		0,38	0,37					(PMMA)	0,25	(PA-GF)	
Exterior & cockpit	1,31%	1,00			0,55					0,10	0,35		
Other automotive parts	0,76%	1,00			0,12						0,13	0,74	
Keep fresh boxes	1,19%	1,00			1,00								
Buckets	0,40%	1,00			1,00								
Waste bins	0,40%	1,00		1,00									
Garden furniture	1,11%	1,00			1,00								
Matresses	0,48%	1,00										1,00	
syringe	0,16%	1,00			1,00								
infusion container	0,11%	1,00				1,00							
soles	0,40%	1,00				0,77						0,23	

Table of mass ratios	Altern. mat. - Total	Stainless steel	Zinc coated steel	Cast iron	Tin plate / Steel packaging	Aluminium	Copper	Glass	Fibrecement	Stoneware	Concrete	Corrug. Board / Cardboard	Paper / fibre cast	Paperbased composites	Wood, textile, etc.	Other
small packaging	1,01				0,33	0,30						0,00	0,22	0,03	0,13	
beverage bottles	12,48				0,04	0,09		12,30						0,06		
other bottles	5,01				0,61	0,01		4,33						0,06		
other rigid packaging	1,91				0,38	0,05		0,16				0,19	0,41	0,27	0,44	
shrink and stretch films	5,94				0,69							3,79	1,07	0,05	0,33	
carrier-bags	2,65												2,65			
other flexible packaging	1,80				0,23	0,12		0,04				0,16	0,64	0,36	0,25	
big drain & sewer pipes	12,58			0,48					0,19	2,84	9,07					
small drain & sewer pipes	5,61		0,18	2,35		0,06			1,50	1,52						
big drinking water pipes	3,63			1,98			0,87		0,78							
small drinking water pipes	4,32	0,43	2,54				1,35									
agricultural pipes	5,61		0,18	2,35		0,06			1,50	1,52						
conduit pipes	1,97	1,97														
gas pipes	6,63	1,34	5,29													
heating & plumbing pipes	2,61	0,76		0,88			0,97									
industry pipes	3,71	0,96		1,76		0,29	0,70									(Mineral wool)
Insulation	3,55							2,31							(Linoleum)	1,23
Floor coverings	2,73							(Foamglass)							2,73	
Windows	1,96					1,34									0,52	0,11
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 5: Substitution model: market share and polymer split of plastic products as well as mass ratios for substitution by alternative materials

		Assumptions for mechanical recycling											
		Total plastics recycling	LDPE	HDPE	PP	PVC	PS	EPS	PET	**PE-X**, PMMA	**ABS**/SAN & oth. thermopl.	PUR	Other thermosets
Packaging	small packaging		5%	5%	5%	5%	5%		5%				
Packaging	beverage bottles								40%				
Packaging	other bottles		30%	30%	30%	30%	30%		30%				
Packaging	other rigid packaging	**26,4%**		20%	20%	20%	20%	20%					
Packaging	shrink and stretch films		65%										
Packaging	carrier bags		30%										
Packaging	other flexible packaging		20%		20%	20%	20%						
Building - Pipes	big drain and sewer pipes	**4%** (% of market input) **11%** (% of available waste)		0%	0%	0%							
Building - Pipes	small drain and sewer p.			5%	5%	15%	of available waste …						
Building - Pipes	big drinking water pipes			0%		0%				0%			
Building - Pipes	small drinking water pipes			5%		15%				5%			
Building - Pipes	agricultural pipes			5%	5%	15%				*wie*			
Building - Pipes	conduit pipes			0%		0%				*HDPE*			
Building - Pipes	gas pipes			70%									
Building - Pipes	heating and plumbing p.				5%					5%			
Building - Pipes	industry pipes			5%	5%	15%				5%	5%		
Building - Non Pipes	insulation	**16% 18%**					0%	0%				0%	
Building - Non Pipes	flooring					5%	(XPS)						
Building - Non Pipes	windows PVC/alum.					50%							
Building - Non Pipes	windows wood												
Electric/ electronic	housing	**6,8%**			5%		5%				12%		
Electric/ electronic	insulation in refrig.						(HIPS)					0%	
Auto-motive	under the hood	**8,3%**		5%	5%					(PMMA)	0%	(PA-GF)	
Auto-motive	exterior and cockpit				20%					5%	20%		
Auto-motive	other automotive parts				0%						0%	0%	
House-wares	keep fresh boxes	**13%**			0%								
House-wares	buckets				5%								
House-wares	waste bins			60%									
Furniture	garden furniture	**5%**			5%								
Furniture	matresses											5%	
Medicine	syringes	**0%**			0%								
Medicine	infusion containers					0%							
Footwear	soles	**0%**				0%						0%	

		Stainless steel	Zinc coated steel	Cast iron	Tin plate / Steel pack.	Aluminium	Copper	Glass	Fibrecement	Stoneware	Concrete	Corrug. Board / Cardboard	Paper / fibre cast	Paperbased composites	**Wood**, textile, etc.	Other
Packaging	small packaging				20%	0%		20%				10%	10%	0%	0%	
Packaging	beverage bottles				60%	50%		60%						0%		
Packaging	other bottles				60%	25%		50%						0%		
Packaging	other rigid packaging				60%	25%		50%				50%	50%	0%	0%	
Packaging	shrink and stretch films				60%							85%	85%	0%	0%	
Packaging	carrier bags												50%			
Packaging	other flexible packaging				60%	25%		50%				50%	50%	0%	0%	
Building - Pipes	big drain and sewer pipes			0%					0%	0%	0%					
Building - Pipes	small drain and sewer p.		20%	20%		20%			0%	0%						
Building - Pipes	big drinking water pipes			0%			0%		0%							
Building - Pipes	small drinking water pipes	20%	20%				30%									
Building - Pipes	agricultural pipes		20%	20%		20%			0%							
Building - Pipes	conduit pipes	0%														
Building - Pipes	gas pipes	70%	70%													
Building - Pipes	heating and plumbing p.	20%		20%			30%									
Building - Pipes	industry pipes	20%		20%		20%	30%									(Mineral wool)
Building - Non Pipes	insulation							0%							(Linoleum)	0%
Building - Non Pipes	flooring							(Foamglass)							0%	
Building - Non Pipes	windows PVC/alum.					60%									0%	
Building - Non Pipes	windows wood															
Electric/ electronic	housing	50%				30%		(Mineral wool)							0%	0%
Electric/ electronic	insulation in refrig.							0%								(rubber)
Auto-motive	under the hood		95%			70%										
Auto-motive	exterior and cockpit		95%			70%		0%								(rubber)
Auto-motive	other automotive parts		95%			70%		0%								20%
House-wares	keep fresh boxes	15%				15%		15%								
House-wares	buckets		15%													
House-wares	waste bins		90%													
Furniture	garden furniture	60%				40%									0%	(latex)
Furniture	matresses	5%														0%
Medicine	syringes							0%								
Medicine	infusion containers							0%							(leather)	(rubber)
Footwear	soles														0%	0%

		Waste?	Sorting residues			Mixed waste		Combustible waste			Other materials	
		Stays in the ground	**Plastics**	**Metals, Glass, Minerals**	**Paper**	**Shredder**	**Residual Waste**	Landfill	En. Recov. - MSWI	En. Recov. - industrial	Landfill	MSWI
Packaging	small packaging		30%	20%	10%	0%	100%	65%	35%	0%	65%	35%
Packaging	beverage bottles		10%	10%	-	0%	100%	65%	35%	0%	65%	35%
Packaging	other bottles		20%	10%	-	0%	100%	65%	35%	0%	65%	35%
Packaging	other rigid packaging		20%	10%	10%	0%	100%	65%	35%	0%	65%	35%
Packaging	shrink and stretch films		5%	5%	5%	0%	100%	65%	35%	0%	65%	35%
Packaging	carrier bags		20%	-	10%	0%	100%	65%	35%	0%	65%	35%
Packaging	other flexible packaging		30%	10%	10%	0%	100%	65%	35%	0%	65%	35%
Building - Pipes	big drain and sewer pipes	100%	-	-	-	-	-	-	-	-	-	-
Building - Pipes	small drain and sewer p.	50%	10%	10%	-	0%	100%	65%	35%	0%	65%	35%
Building - Pipes	big drinking water pipes	100%	-	-	-	-	-	-	-	-	-	-
Building - Pipes	small drinking water pipes	50%	10%	10%	-	0%	100%	65%	35%	0%	65%	35%
Building - Pipes	agricultural pipes	50%	10%	10%	-	0%	100%	65%	35%	0%	65%	35%
Building - Pipes	conduit pipes	20%	10%	10%	-	0%	100%	65%	35%	0%	65%	35%
Building - Pipes	gas pipes	50%	10%	10%	-	0%	100%	65%	35%	0%	65%	35%
Building - Pipes	heating and plumbing p.	20%	10%	10%	-	0%	100%	65%	35%	0%	65%	35%
Building - Pipes	industry pipes	20%	10%	10%	-	0%	100%	65%	35%	0%	65%	35%
Building - Non Pipes	insulation	20%	-	-	-	10%	90%	58%	42%	0%	68%	32%
Building - Non Pipes	flooring		10%	-	-	0%	100%	65%	35%	0%	65%	35%
Building - Non Pipes	windows PVC/alum.		5%	5%	-	0%	100%	65%	35%	0%	65%	35%
Building - Non Pipes	windows wood					0%	100%	32%	18%	50%	0%	0%
Electric/ electronic	housing		5%	5%	-	30%	70%	71%	28%	2%	75%	25%
Electric/ electronic	insulation in refrig.		10%	-	-	30%	70%	71%	28%	2%	75%	25%
Auto-motive	under the hood		5%	10%	-	100%	0%	85%	10%	5%	100%	0%
Auto-motive	exterior and cockpit		5%	10%	-	100%	0%	85%	10%	5%	100%	0%
Auto-motive	other automotive parts		5%	10%	-	100%	0%	85%	10%	5%	100%	0%
House-wares	keep fresh boxes		10%	10%	-	0%	100%	65%	35%	0%	65%	35%
House-wares	buckets		5%	5%	-	0%	100%	65%	35%	0%	65%	35%
House-wares	waste bins		5%	5%	-	0%	100%	65%	35%	0%	65%	35%
Furniture	garden furniture		5%	5%	-	30%	70%	71%	28%	2%	75%	25%
Furniture	matresses		10%	10%	-	30%	70%	71%	28%	2%	75%	25%
Medicine	syringes		-	-	-	0%	100%	65%	35%	0%	65%	35%
Medicine	infusion containers		-	-	-	0%	100%	65%	35%	0%	65%	35%
Footwear	soles		-	-	-	0%	100%	65%	35%	0%	65%	35%

Table 6: Distribution of analysed products at end-of-life to waste management options in the calculation model (recycling shares; sorting residues of waste collected for recycling; distribution of remaining waste mass to MSWI, industrial energy recovery and landfill)

Table 7 shows the time series of different plastic packaging materials. The energy and GHG emission savings due to a mass reduction of the functional unit is up to 28 % since 1991. The improvement of production processes to produce the plastic packaging (at 5 % maximum) is significantly lower than for mass reduction and in some cases values are even slightly negative.

Packaging	Time period	Mass [kg/kg]	Energy [MJ/kg]	CO2-EQ [kg/kg]
Milkshake container 500ml	1991-2009	-27,6%	-3,2%	-2,2%
Cream container 200g	1991-2009	-19,2%	-4,8%	16,6%
Condensed milk portion pack 10 g	1991-2009	-15,8%	-4,8%	16,6%
Liquid washing agent bottle 1.500 ml	1991-2009	-23,4%	-3,2%	-2,2%
Catering pack (for e.g. jam) 12,5 kg	1991-2008	-22,3%	4,1%	-2,8%
Still mineral water bottle 1.500 ml	2000-2009	-21,7%	2,5%	1,0%

Table 7: Development of packaging efficiency versus ecoprofile effects.

Figure 5 shows GHG emissions in production, use and waste phase of a 2,5 MW windmill rotor made of glass fibre reinforced plastic (1/3 of the total use benefit of the windmill was allocated to the rotor) and of plastic film used for a thin film photovoltaic module with a peak power of 1 kWp (1/4 of the total use benefit of the photovoltaic module was allocated to the plastic film).

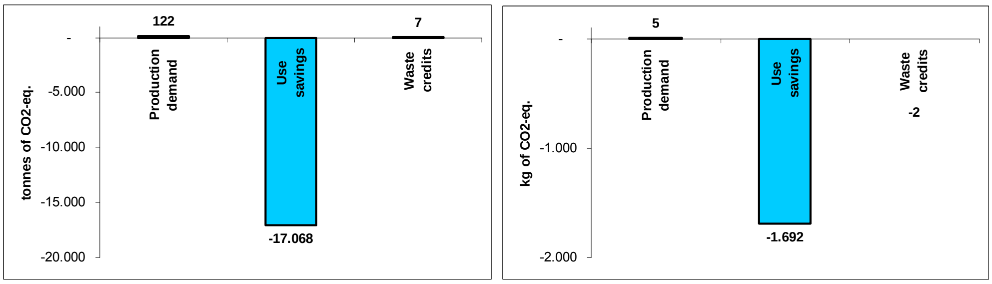

Figure 5: GHG emissions in production, use and waste phase of a 2,5 MW windmill rotor made of glass fibre reinforced plastic and of plastic film used for a thin film photovoltaic module with a peak power of 1 kWp.

In Table 8 the values for the production and the waste management of 0,5 litre beverage bottles made of PLA[6] and PET were combined with results of the total life cycle (min-max ranges, no processing from granulate to bottles included).

[6] Swiss ecoinvent database has two data sets for PLA [Ecoinvent 2007]. PLA bottle grade stands for PLA produced in Europe. PLA Natureworks stands for PLA produced in Nebraska, USA. Ecological data set for PLA Natureworks is significantly favourable because of the energy supply of the wind park. Furthermore greenhouse gas emissions are compensated with investments in wind parks.

GWP 100a g CO2-eq. / 0,5 l bottle	Production		Waste management		Total life cycle	
	min	max	min	max	min	max
PLA bottle grade US	55	58	-41	53	14	110
PLA bottle grade GLO	72	75	-61	53	10	128
PET bottle grade GLO	61	61	-59	17	2	78

Table 8: Global warming potential (min-max) of 0,5 l beverage bottles made of PLA or PET, depending on production conditions of PLA and even more on effects of different waste management options[7].

As shown in Figure 6 the GWP of all case studies examined are within a broad range. For the renewable this is a result of the choice of the renewable resource (use of corn, wheat, sugar beet, sugar cane, etc.) and also the type of waste management treatment applied. In the case of fossil fuel the range is a consequence of different waste management options.

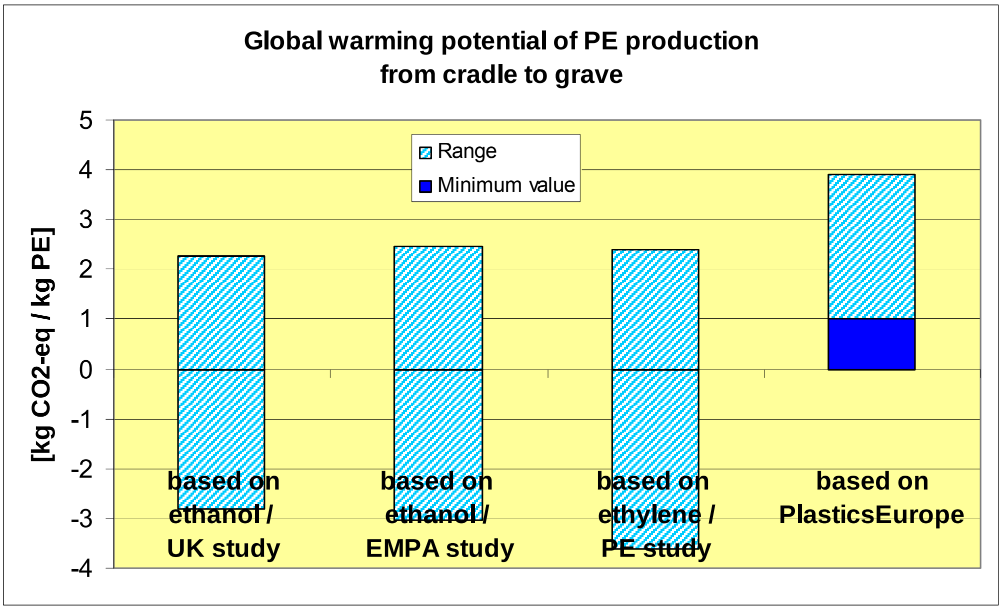

Figure 6: Possible ranges of total life-cycle GHG emissions for PE film produced from renewable resources (column 1-3) and fossil resources (last column).

Figure 7 shows that all recycling and recovery options result in net-savings of energy resources. Furthermore it discovers that the benefits of material recycling can become comparable or even lower than the benefits of feedstock recycling or industrial energy recovery, in cases where material recycling produces high material losses or where the mass of substituted virgin material is considerably lower than the recycled plastic mass.

[7] Based on Ecoinvent nomenclature: US – United States, GLO – Global) [Ecoinvent, 2007].

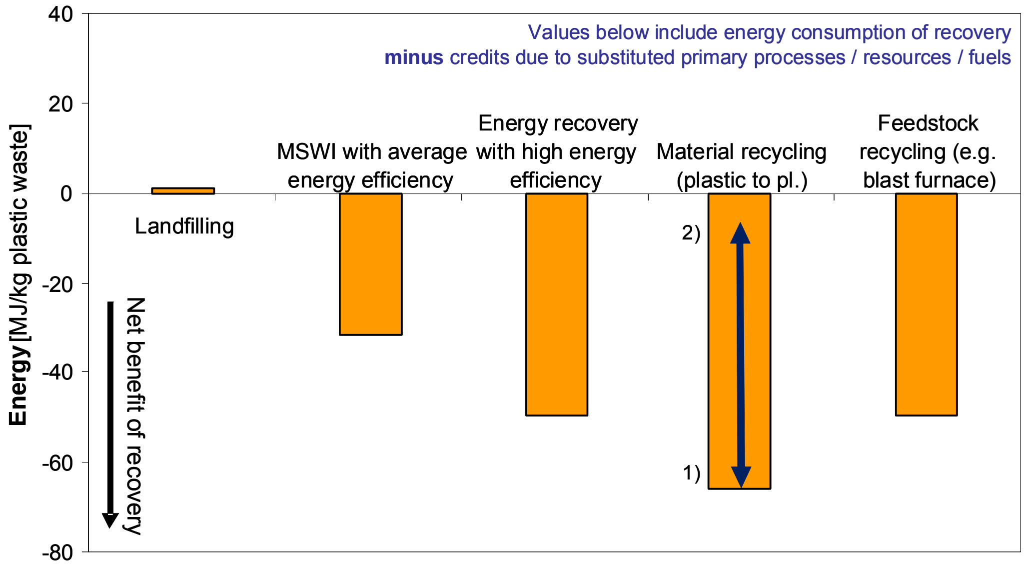

Figure 7: Net energy effects of recycling, recovery and disposal processes for LDPE, extracted from the waste management calculation model used in Part 1 of this study. Impacts of collection, sorting and recycling processes as well as credits due to substituted primary production and substituted primary fuels are already summed up in the figures above[8]

As seen in Figure 8 GHG emissions are also reduced by material and feedstock recycling and by energy recovery with high energy efficiency. Energy recovery of plastic waste in MSWI plants at current European conditions produces more CO_2 emissions than it prevents due to substituted electricity and district heat production.

[8] (1) Values for material recycling are based on 10 % material losses during recycling process and assume that recycling product substitutes same mass of virgin material.
(2) Benefits of material recycling considerably decrease with higher material losses and/or if not virgin plastics, but materials like concrete or wood are substituted (e.g. poles, roofing tiles, etc. [IVV, 1999]).

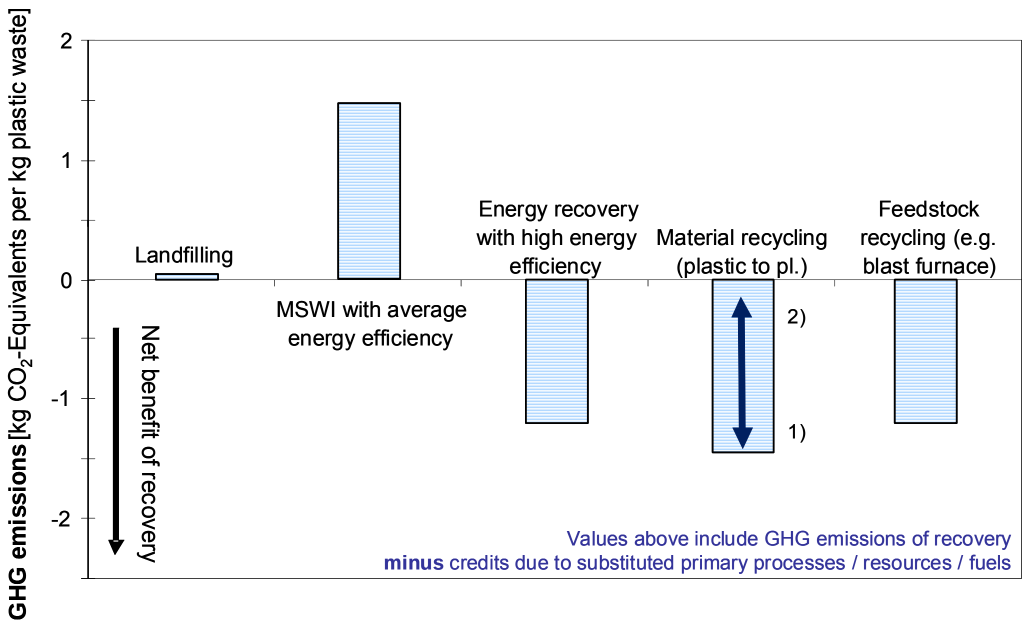

Figure 8: Net GHG effects of recycling, recovery and disposal processes for LDPE, extracted from the waste management calculation model used in Part 1 of this study. Impacts of collection, sorting and recycling processes as well as credits due to substituted primary production and substituted primary fuels are already summed up in the figures above[9]

Figure 9 shows a comparison of the GHG-benefits of the waste strategies "full compliance with the EU directives on packaging, ELV and WEEE" and "diversion of mixed residual waste from landfills". In scenario A energy recovery is only covered by MSWI plants, scenario B also industrial energy recovery and feedstock recycling processes are considered.

[9] (1) Values for material recycling are based on 10 % material losses during recycling process and assume that recycling product substitutes same mass of virgin material.
(2) Benefits of material recycling considerably decrease with higher material losses and/or if not virgin plastics, but materials like concrete or wood are substituted (e.g. poles, roofing tiles, etc. [IVV, 1999]).

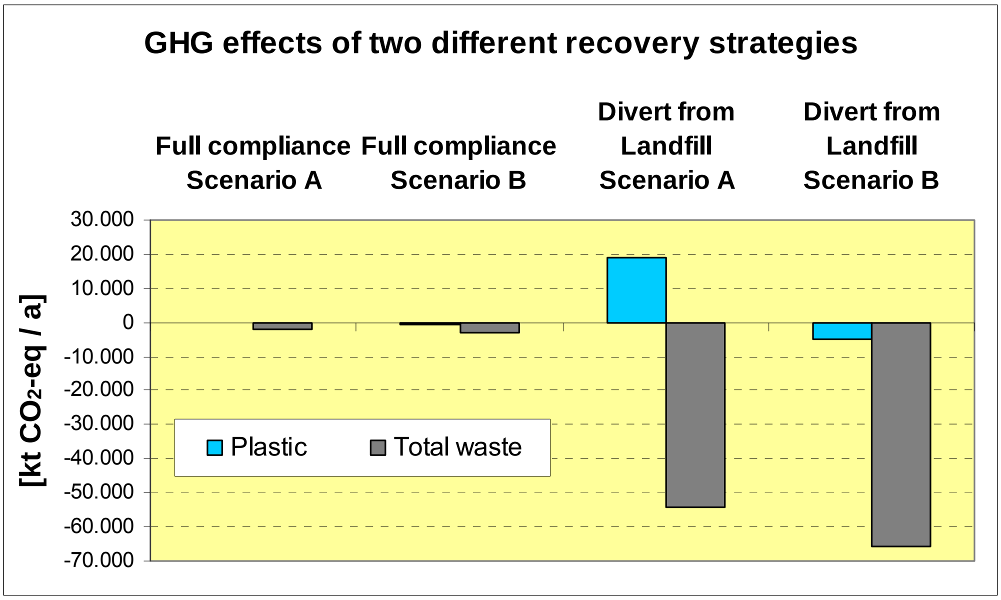

Figure 9: Comparison of the GHG-benefits of the waste strategies "full compliance with the EU directives on packaging, ELV and WEEE" and "diversion of mixed residual waste from landfills".

Table 9 shows a rough estimation of the possible magnitude of CO_2 savings resulting from prevented food losses enabled by plastic packaging for fresh food.

Food Group	CO2 saved from 10% prevented food losses per CO2 pack. production	CO2 saved from 20% prevented food losses per CO2 pack. production
fresh fruit	1,9	3,8
fresh vegetables & salads	1,0	1,9
sausage & cold meat products	3,7	7,4
fresh meat incl. poultry	13,3	26,6
sweet biscuits, cakes, pastry	1,5	2,9
cheese	13,1	26,1
savoury biscuits & crackers	1,5	2,9
Weighted average	**4,7**	**9,5**

Table 9: Saved CO_2 emissions due to 10 % resp. 20 % prevented food losses divided by CO_2 emissions of packaging production.

7 APPENDIX B: Critical Review Reports

Review Statement

following the

Critical Review

of the study by denkstatt for Plastics Europe:

"The Impact of Plastics on Life Cycle Energy Consumption and GHG Emissions in Europe:

Part 1: Current Status & Future Scenarios &

Part 2: Additional Arguments on Benefits of Plastics for Energy Efficiency & Climate Protection"

Critical review carried out by:

Adisa Azapagic

School of Chemical Engineering and Analytical Science

The University of Manchester

July 2010

1 Background

This report summaries the findings of a critical review of the study "The Impact of Plastics on Life Cycle Energy Consumption and GHG Emissions in Europe, Parts 1&2". The study was carried out by denkstatt for Plastics Europe.

This critical review was commissioned by Plastics Europe.

The critical-review process involved the following steps and activities:

- a meeting with denkstatt and Plastics Europe, during which the preliminary results of the study and the scope of the critical review were discussed;
- a review of the draft study report and the results (Parts 1&2), followed by a draft critical-review report which made a number of specific recommendations for improvements to the study;
- a review of the final study report (Parts 1&2 and Executive Summary), in which the authors of the study addressed most of the points as suggested in the draft critical review; and
- the final critical review report (this review statement).

The following sections present the findings of the critical review based on the study final report (Part 1&2, June 2010).

Although the international standards for Life Cycle Assessment (ISO 14040:2006 and 14044:2006) are not applicable to this study, the critical review has followed the main guiding principles defined in these standards. Thus, it should be noted that it is not the role of this critical review to endorse or dispute the goal of the study and the related conclusions but rather the aim was to:

- examine that the methods used are scientifically and technically valid given the goal of the study;
- that the data used are appropriate and reasonable in relation to the goal of the study;
- that the interpretation reflects the goal of the study and the limitations identified; and
- that the study report is transparent and consistent.

Therefore, the findings of this review are discussed in accordance to the above guiding principles.

The critical review did not involve a review of the data used in the study so that all the findings of the review presented here are based solely on the final reports and the discussions with the authors of the study and Plastics Europe.

Since Part 1 and Part 2 of the study had slightly different goals and used a different approach, they are discussed separately in this report.

2 Critical-review findings

2.1 Part 1

Part 1 represents an update of the GUA/denkstatt study "The Contribution of Plastic Products to Resource Efficiency", carried out in 2004/2005.

The main goal of the updated study was to estimate the life cycle energy consumption and GHG emissions of typical plastic products and to compare this to a range of alternative materials which could realistically replace plastics (or vice versa). The ultimate goal was to "demonstrate that the use of plastics can in many cases actually help save resources." (Part 1, section 1.1).

The scope of the study is from 'cradle to grave' and the focus is on two environmental aspects: energy consumption and GHG emissions. Although the study considers the whole life cycle of products, it is not LCA according to ISO 14040 and 14044, due to the limited number of environmental aspects considered. Furthermore, the study does not compare plastics and alternative materials in individual products, but rather gives an estimation of the impacts at the whole-market level, covering all plastics applications across Europe (EU27+2).

The plastic materials and products are compared to alternative materials which can substitute plastics in these products without any change in the design, function or service rendered by the product. It was found that only 16% of the total market of plastic products cannot be replaced realistically by other materials, without these changes. Due to data limitations, only 75% of substitutable plastic products (173 in total) are covered by the study (Part 1, Tables 2&3).

The study follows the "80/20" approach (see Part 1, section 1.2), whereby 80% of the results are obtained at 20% of effort.

Given the above limitations, this critical review has found that, overall, this represents a thorough and competent study of the life cycle energy consumption and GHG emissions of plastic materials and products. The study assumptions are reasonable; in many cases conservative assumptions have been made to ensure that plastics is not unduly favoured over other materials.

The data sources appropriate, as far as possible, given the "80/20" approach and the other constraints of the study. Arguably, in many respects the study goes beyond the "80/20" method and assumes a much more rigorous approach, as demonstrated by depth of analysis in some cases (where data availability allowed) as well as the uncertainty and sensitivity analyses carried out.

The scope of the study is extensive so that a large number of assumptions and extrapolations have had to be made. Nevertheless, while the results at the level of specific products may not be completely accurate, the overall results are sufficiently valid.

The interpretation of the results is appropriate given the assumptions, limitations and the data used. It should be noted that most data on plastics are sourced from Plastics Europe who commissioned the study – however, these data are recognised internationally as a reputable source and are used widely by LCA practitioners. The data for other materials and products are taken from various reputed sources in the public domain, including manufacturers' data. Ecoinvent database has also been used extensively.

The study report is very detailed, transparent, consistent and balanced.

However, it should be borne in mind that this is a broad-brush, sectoral-level analysis and that large uncertainties exist, as demonstrated in the study. Moreover, there is no internationally accepted methodology for such analyses and as such, they are open to scrutiny and interpretation. Nevertheless, this study uses the state-of-the-art methodology and is transparent enough to enable an informed debate on the issues raised.

2.2 Part 2

The second part of the study considers further aspects of the use of plastic materials, both today and in the future (2020). These include improvements of plastics over time (increased material and production efficiency); the use of renewable feedstocks for plastics production; the use of plastics in generating renewable energy; prevented food losses through the use of packaging; benefits of increased insulation; and effects of different end-of-life strategies.

Part 2 follows a different approach to Part 1: it presents "exemplary facts and figures" with a decreasing degree of detail, using "rough estimations and semi-quantitative arguments" (Part 2, section 1.1). As stated in the report: "The goal is to produce information on trends, ranges, orders of magnitude rather than to produce specific/reliable results." Here, only plastics is considered and, appropriately, no attempt at comparison with other materials has been made.

The critical review of this part was not as detailed as that of Part 1 (as agreed at the outset) and has considered only the general assumptions, data sources and interpretation of the results. These have all been found to be appropriate, given the goal of the study.

However, it should be borne in mind that, similar to plastic products, products made from alternative materials will also change (improve) over time and in some cases could also have similar beneficial effects (e.g. benefits of insulation are not so much material-dependent) so that no direct comparison between plastics and other materials is possible or appropriate. This is stated clearly in the conclusions of the report.

3 Final remarks

This study has only considered two sustainability aspects: energy consumption and GHG emissions associated with plastic materials and their possible substitutes. As acknowledged in the report (Executive Summary, section 4), comparison of products and materials should not only be based on these two criteria, but should involve a much more comprehensive sustainability assessment, covering all relevant environmental, economic and social effects of the investigated materials and products.

Furthermore, the conclusions of the study are based on the assumption that plastic is replaced by alternative materials without any changes in the design, function or service of the products studied. Again, as acknowledged in the study report (Part 1, section 6), this is a limitation of the study as changes in the design and function can often have a bigger impact on the total energy demand and GHG emissions than different materials. This should be borne in mind when interpreting and discussing the results of this study.

The impact of plastics on life cycle energy consumption and GHG emissions in Europe

Critical Review Report

by

Roland Hischier

for

PlasticsEurope (Association of plastics Manufacturers)

Brussels (Belgium)

Date

June 27, 2010

Status

Final Version

1 Origination and Course of Action

The herein described critical review process, commissioned by PlasticsEurope (Association of Plastics Manufacturers), has been established in the timeframe of April 2009 to November 2009, plus an additional review of updates for the cases “windows” and “insulation” in June 2010. Although the examined study is not a traditional life cycle assessment (LCA) study according to the ISO EN DIN 14040 series [1a+b], a critical review process in the spirit of the terms of ISO series [1a] has been established. This on hand critical review report is based on the **final report, dated June 2010.** Its final version will be integrated in the very final version of the summary report of this study here.

The study has been established by collaborators of Austrian company denkstatt GmbH, Wien, Austria. The review team consisted of two persons – Professor Adisa Azapagic, University of Manchester (United Kingdom), and Mister Roland Hischier, Empa St. Gallen (Switzerland).

This report here summarizes only the comments from Roland Hischier – respective comments from Adisa Azapagic are summarized in a separate document.

Besides the above mentioned report, the reviewers got additionally multiple draft versions of all parts of the report, as well as several power point presentations with first results during the two meetings as well as in-between these meetings. The critical review was established as a so-called **accompanying survey**, i.e. the reviewers were involved already in a rather early stage of the study, and thus had the possibilities to influence the further development of the whole study from that moment on.

The work of the two reviewers took place in a very open and friendly ambiance; all requested documents were delivered by denkstatt. The commissioner of the study (PlasticsEurope) was involved in all technical arbitrations and showed a very special interest in an irreproachable and professional execution of the complete study. One of their important points was e.g. that the alternative materials are based on conservative estimations in order not to overestimate the effects of plastics. All in all, the reviewer experienced the complete process as well as the dependency triangle between commissioner, authors of the study and reviewer very positive.

Within the framework of the complete review process, the following meetings took place:

1st meeting: April 24, 2009 in Vienna

2nd meeting: June 25, 2009 in Brussels

Within the current review procedure, no meeting for an in-deep examination of the used calculation model took place. However, this has been judged not to be a problem, as denkstatt used the same calculation model as for the 2004/5 study "the contribution of plastic products to resource efficiency" [2] – study that has already been reviewed by Mister Roland Hischier. Then, such an examination of the calculation model took place, allowing to the reviewer to verify, by random samples, the voluminous calculation work done within the framework of the study.

2 Comments about the report

2.1 Criteria

The whole review process is based on the expectations of the commissioner concerning the review process, expressed during the very first meeting in Vienna, as well as the criteria mentioned in ISO EN DIN 14040 [1a]. In details, the following criteria have been examined for this study here:

- *Is the method, as well as the 80/20 approach, scientifically sounded & reasonable within the goal of the study?*
- *Are the used data sufficient & appropriate in respect of the goal of the study?*
- *Does the conclusion take into account the recognized limitations of the study, especially in the framework of the original aim of the study?*
- *Is the report transparent and coherent?*

2.2 Scientific background and Practicability of the used Method, the used 80/20 approach

This study had never the aim of establishing a complete "classical" LCA study according to the international ISO standards [1a+b] and thus cannot be compared with those standards in the framework of the critical review process here.

According to the commissioner, this study shall create data in form that PlasticsEurope has afterwards the necessary background information for questions / criticism of plastics in the context of sustainable development (SD); with a focus on the two aspects of energy use and climate change. A focus on these two aspects is valuable, as plastics are made from fossil resources and thus, the use of these resources as well as the influence on climate change are among the most relevant environmental impacts. In addition – having in mind the addresses of the report – these two aspects are among the most discussed in the framework of current environmental policies.

The authors of the study at denkstatt have put a lot of efforts in developing a transparent and logical, stepwise method already for the precursor study in 2004/5 [2] – method that has been judged by the reviewer already at that time as "scientifically adequate and (…) also to be manageable within a reasonable timeframe" (see review report in [2]). The review this time is thus rather focused on the applied 80/20 approach; in order to approve this approach for the commissioner of the study and to give them the necessary insurance for a presentation of the results of this report towards their various stakeholders.

The whole study is actually split into two parts – an update (and expansion) of the mentioned former study [2] and an additional examination of various further aspects of the use of plastics. In accordance with the commissioner of the study, this second part of the report has not been reviewed in-depth; rather its general lines and conclusions have been critically examined. Taking the 80/20 spirit of the overall work here, I can conclude for this second part of the study that the methodological efforts reported are in accordance with this approach. For part I of the study, the authors included even more case studies and more information than in the former study [2] – and thus it can be concluded that the stated 80/20 approach is largely fulfilled by the first part of the study.

All in all, the applied 80/20 approach can be qualified as an adequate approach for this study here; resulting in a reasonable narrow range of results in order to establish conclusions that are stable in their basic direction.

For the aggregation of the considered air emissions factors to one common global warming potential value, the method used is taken from the most recent developments in the field of LCA (see e.g. [3]).

2.3 Appropriateness of data

The consultants at denkstatt have already a long tradition and thus also a long-lasting experience with system analysis projects handling big amounts of data, especially in the field of waste treatment and waste strategies. Within the data collection for this study here, this knowledge and experience has been used (again) as far as possible.

In the framework of this study here, data on the following levels have been used:

1. data about the market situation of the various plastics
2. characteristics of the plastic parts and their respective alternatives in other materials during production, use and disposal
3. data about the energy consumption and the global warming potential of all materials

In comparison with the former study [2], part 1 of this study here covers now with EU 27 plus Norway plus Switzerland, almost twice as many countries as before. The market data collected represent the situation on the Western European market in 2007 and cover almost 90% of the market; about 75% of the substitutable plastics are covered by the 32 case studies analysed. For the life cycle information of the different materials, up-to-date literature and databases representing Western European conditions have been used. Energy consumption during the use phases has been calculated based on adequate technical information and expert judgment. The quality of the various datasets used is more than sufficient for this type of study. Under the aspect of the 80/20 approach it can be concluded that part 1 of the study goes clearly beyond this objective.

For part 2 of this report, the authors declare clearly that the degree of details – and thus the quality of the used data – is decreasing across chapter 2. Nevertheless, taking into account the 80/20 rule, it can be concluded that the chosen data sources are appropriate for the scope of this part of the study.

2.4 Conclusions of the Report

Like all other parts of the two reports also, the respective chapters (results, sensitivity analysis, conclusions) of both parts (i.e. part 1 and part 2) are presented in a very detailed, and also very transparent and logic manner. In addition, a summarizing document has been produced by the authors of this study – summarizing the results in a very clear and – despite its length of less than 30 pages – comprehensive manner; allowing to an interested party to get a overview of all results without reading the comprehensive reports of part 1 and part 2.

The study tries to stipulate in a very clear and comprehensive manner the limitations due to the chosen approach and the available data. In the final chapter “Conclusions” of the mentioned summarizing document, a clear link back to the limitations of the approach chosen for this study can be found – especially …

… that part 1 of the study examines only the replacement of plastic materials by other materials --> thus, it is not examined if changes in “how things are done” would influence the total energy consumption to what extend; and

… that for a comprehensive comparison more aspects than just energy consumption and global warming potential should have been examined.

All in all this gives an adequate and complete picture from the total of all efforts as well as the limits that are behind these reports here.

2.5 Transparency and Coherence of the Report

The reporting of this study is split into three parts: (i) a summary report, (ii) a detailed report covering part I of the study, and (iii) a detailed report covering part 2 of the study. All these three documents are for themselves clear and logic in their respective structure and properly designed. Due to their extensive size however, the two detailed reports of part 1 and 2 can not be considered anymore as easy understandable documents to read through. They rather have to be considered as specific and comprehensive reference documents due to their detailed information content for all examined aspects. All these details are however presented in a very clear and transparent manner, allowing a quite easy overview of the various parts of this study.

The summary report – as the main document for the communication of the finding of this study – presents the results in a very clear, logic and thus easy understandable form.

3 Summary and Conclusion

The complete study has been established in a transparent and logic way, based on an even more comprehensive compilation – in comparison to [2] – of market and other information. The intended 80/20 approach is fulfilled in all parts of the study. All three documents of the report are clear and transparent and I would clearly recommend a publication of these reports.

4 References

[1a] International Standard (ISO): Environmental management - Life cycle assessment - Principles and framework. Standard ISO 14040:2006 (2006).

[1b] International Standard (ISO): Environmental management - Life cycle assessment – Requirements and Guidelines. Standard ISO 14044:2006 (2006).

[2] Pilz, H., Schweighofer, J. & Kletzer, E. (2005): The Contribution of Plastic Products to Resource Efficiency, PlasticsEurope - Association of Plastics Manufacturers, Brussels, Belgium.

[3] Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Hischier R., Hellweg S., Humbert S., Margni M., Nemecek T. and Spielmann M. (2007): Implementation of Life Cycle Impact Assessment Methods. Final report No. 3, ecoinvent data v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.ch.

St. Gallen, June 27, 2010

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