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SUSTAINABLE MANAGEMENT AND RECOVERY POTENTIAL OF NON-PACKAGING PLASTIC WASTE FROM THE COMMERCIAL AND PRIVATE HOUSEHOLD SECTORS

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NOTE FROM THE SECRETARIAT

In addition to aluminum, wood fibres and critical metals, plastics have been identified as an important material for which a sustainable materials management approach might provide valuable insight. The objective of this case study on plastics is to analyse the environmental impacts of plastics throughout their lifecycle and to explore policy opportunities and barriers for SMM, as a way of demonstrating the utility of the SMM concept for policy-making.

This case study was presented at the OECD Global Forum on Sustainable Materials Management held in Belgium from 25 to 27 October 2010, together with other policy and case study materials.

This draft case study on plastics was prepared by Mr. Ingo Sartorius of PlasticsEurope Deutschland e.V. in cooperation with Mr. Joachim Wuttke from UBA (the German Federal Environmental Agency).

Due to constraints on time and resources, this study is a partial approach of sustainable materials management insofar as it focuses mainly on the end of life of plastic materials. It is however published as such.

The opinions expressed in this paper are the sole responsibility of the author(s) and do not necessarily reflect those of the OECD or the governments of its member countries.

The secretariat would like to thank Germany for the contribution of this case study.

TABLE OF CONTENTS

NOTE FROM THE SECRETARIAT 2
EXECUTIVE SUMMARY 5
RÉSUMÉ 7
GLOSSARY OF ACRONYMS 10
I - INTRODUCTION 11
II - SCOPE AND OBJECTIVES 12
III - PLASTICS PRODUCTION AND CONSUMPTION 13
1. Plastics Production and Consumption in Europe 13
2. Half of all Plastic Waste is recovered 13
3. A Landfill Ban is a Major Incentive 15
4. Plastics Production and Use in Germany and Resources Consideration 15
IV - AN OVERVIEW OF PLASTIC WASTE 19
1. Management of Plastic Waste 19
V - RECOVERY OPTIONS 25
1. Suitable for Material Recycling 25
2. Feedstock Recycling and Energy Recovery 26
VI - ENVIRONMENTAL ASSESSMENT 27
1. Scenarios for Material Recycling 28
2. Scenarios for Energy Use 28
3. The Influence of Resource Yields 29
4. Observations on the Choice and Determination of Criteria 29
5. Sensitivity Analysis 30
6. Significance of the Results 30
7. Conclusions and Recommendations Resulting from the Environmental Analyses 31
VII - ECONOMIC ASSESSMENT 33

VIII - THE KEY FINDINGS ... 34
IX - CONCLUSIONS ... 36
X - INFORMATION SOURCES ... 37

Figures

Figure 1: Plastics value chain from production to end-of-life in 2007 (EU27+ Switzerland and Norway ... 14

Figure 2: Distribution of processed plastics by sector in Germany, 2007 ... 16

Figure 3: Proportion of each plastic type processed in Germany in 2007 ... 16

Figure 4: Plastics processing; proportion of plastic types used in the packaging, construction, automotive, electrical/electronic and other industries in Germany in 2007 ... 17

Figure 5: Proportion of post-consumer waste by sector, 2007 ... 20

Figure 6: Distribution of plastics types in total waste plastics ... 20

Figure 7: Amounts of recovered plastic waste by application (in kt ... 21

Figure 8: Plastic waste recovery and landfill by origin (in kt ... 22

Figure 9: Recovery of post-consumer waste in Germany 2007 ... 22

Figure 10: Development of post-consumer plastics waste and post-industrial plastics waste quantities (in kt) ... 23

Figure 11: Quantities of waste going to recovery and disposal ... 23

Figure 12: Expansion of waste recovery (in kt) ... 24

EXECUTIVE SUMMARY

Background

Due to its versatility, plastic constantly makes new functions for products possible which can hardly be substituted by others. Plastics are not only a cost-effective, but above all also a very resource-efficient material as the products generally save more than double the amount of energy used to manufacture them. This saving effect has been demonstrated in numerous LCAs. For example, in connection with plastic packaging, KOOIJMAN (1996) showed that in an ecological assessment of foodstuff during the entire process chain, the energy required for the plastic packaging, which protects the food products from spoiling, constitutes only 11%. The agricultural production and processing of foodstuff account for the largest proportion, namely 49%, and the remainder is made up by transport (6%) and household (34%) for cooking and cooling.

Another impressive example of the enormous savings potential of plastic products are insulating materials in house building, where according to a study by the Fraunhofer Institute for Systems and Innovation Research (ISI) [1999], the energy required for the production of polymer thermal insulation material made of plastics pays for itself in energy-saving terms within the first year of use. Also known are the saving effects that can be achieved in cars through lightweight construction and improved engine efficiency using plastics: a car weighing 100 kg less uses about 0.2 litres less fuel per 100 kilometres.

Today, plastics are predominantly made from crude oil or natural gas. Once the products have served their purpose, the energy used to produce them should not remain unused, especially as the calorific value of the products is practically 1:1 that of the raw material used. This, to a certain extent, “parked” energy can be materially or energetically utilised at products’ end-of-life stage, depending on the shape and quality of the plastic waste. Across Europe more than 50% of plastic waste is reutilised in one of these ways, Nine European countries, that have established a good waste management infrastructure, show recovery rates above 80% related to plastics waste, while the majority of European countries like Poland and the UK recover less than 30%.

Over 60% of plastic waste comes from packaging, which makes up by far the predominant proportion in material recycling. Recycling processes for packaging are not only technologically advanced, but have also been extensively studied in relation to their ecological efficiency. Fundamental to this are, for example, the LCA analyses of the various methods of recovery pathways from plastic packaging household waste carried out by HEYDE/KREMER (1999), which have been supplemented by numerous further studies.

On the other hand, comparatively less developed and researched are the recycling and recovery potentials of plastic waste which does not come from packaging but also originates from the commercial and private household sectors. This is the background to the knowledge currently available relating to this field being summarised in this study in the form of a desk review.

Subject matter of the desk reviews

The core of the review is a study commissioned by the German Federal Environment Agency (UBA) together with the German Association of Plastics Manufacturers finalized in 2006 to analyse the recycling potential of plastic waste other than the separately collected packaging, which is largely regulated.

This relates both to plastics in private household waste, for example, in residual waste and bulky waste collections, and to other plastics in commercial waste. As part of the study, in which several institutes participated and which is made up of seven sub-reports, these types of special waste were quantified, their nature described and categorised. But above all, possible options for recovering this waste underwent a comprehensive ecological performance analysis and were also economically evaluated. For the purpose of verification and correction, the ecological and environmental assessments are based on the international standard ISO 14040 and, additionally, a critical review by independent peers has been performed.

In view of the fact that there is quite a large amount of data available concerning the environmental effects of plastic products during their entire life cycle, the ecological performance analyses considered here concentrate on the waste phase, as significant differences in the environmental performance result in the various options for handling the waste. However, the ecological performance analyses relate to sometimes very different and complex processes so that the results can only form an initial orientation, but not a valid basis for taking decisions in individual cases. For a better classification of the results the present paper also gives an overview of the production, consumption and waste quantities, whereby the data relates to the year 2007.

Results

Ultimately the ecological analysis of the options for recovering plastic waste outside the field of packaging has not found an all-encompassing solution that could apply to all types of waste. What is certain, as also shown by more recent studies (*e.g.* “Climate protection potentials of waste management” 2010 commissioned by the UBA), is that every form of recovery is better than dumping. However, there is not one recovery path that is superior to another. In the end, criteria such as the origin quality and quantity of the waste flow are of decisive importance in selecting the best possible form of recovery in each case.

From a purely ecological point of view, material recycling has advantages over other forms of reutilisation in certain circumstances, if waste can be separated in an easily identifiable manner in sufficiently large quantities and without great cost and effort. In such cases it makes ecologically sense to remove as much specified plastic waste as possible from household waste in order to use the material again. Typical examples are PET bottles or polyolefin films that are sorted out for recycling. In addition, there must be markets available for the products resulting from the recycling processes *i.e.* markets for products made of plastics recyclates.

It is a similar picture with bulky waste and commercial waste. If the plastics can as far as possible be sorted by type with little cost and effort, material recycling has ecological benefits. But where material recycling is not feasible in a technically or an economically efficient manner, such as in the case of mixed or contaminated waste, energy recovery is the better solution. Particularly, if economic aspects are also taken into consideration, energy recovery and in individual cases also raw material recovery processes such as utilizing material properties as reducing agent in blast furnaces are at least of equivalent value or even superior.

In principle, it can be concluded, that efficient waste management consists in the best possible mix of all recovery processes. Decisive are the constraining factors that apply locally: collection structures by municipalities or by private organisations and waste qualities and yields, and - what is of key importance - the marketability of the resulting products from the recovery operation, whether they are recyclates, chemical feedstock or energy.

RÉSUMÉ

Généralités

Grâce à sa polyvalence, le plastique permet de créer sans cesse de nouvelles fonctions de produit difficiles à reproduire par d'autres moyens. Les plastiques constituent non seulement un matériau d'un bon rapport coût-efficacité, mais aussi et surtout un matériau très sobre en ressources, puisque les produits correspondants permettent généralement d'économiser une quantité d'énergie plus de deux fois supérieure à celle nécessaire à leur fabrication. Ce bénéfice en termes d'économies d'énergie a été démontré par de nombreuses analyses du cycle de vie. Ainsi, dans le cadre d'une évaluation écologique des aliments portant sur l'ensemble de la chaîne de production, KOOIJMAN (1996) a montré que l'énergie nécessaire aux emballages plastiques qui évitent aux aliments de s'abîmer représentait seulement 11 % du total. Ce sont la production et la transformation des produits agricoles qui consomment le plus d'énergie (49 %), la part restante correspondant au transport (6 %), ainsi qu'à la réfrigération et à la cuisson des aliments par les particuliers (34 %).

Les matériaux isolants utilisés dans le bâtiment offrent une autre illustration éloquente des formidables économies que peuvent permettre de réaliser les produits plastiques : d'après une étude du Fraunhofer Institute for Systems and Innovation Research (ISI) [1999], l'investissement en énergie nécessaire pour fabriquer les matériaux polymères utilisés pour l'isolation thermique est amorti dès la première année d'utilisation grâce à la diminution de la consommation d'énergie. D'autres économies peuvent être obtenues dans l'automobile, où on sait que les plastiques permettent d'alléger les véhicules et d'améliorer le rendement des moteurs : ainsi, une réduction du poids de 100 kg abaisse la consommation de carburant d'une voiture d'environ 0.2 litre aux 100 kilomètres.

Aujourd'hui, les plastiques sont surtout produits à partir de pétrole brut ou de gaz naturel. Lorsque les produits arrivent en fin de vie utile, il importe de ne pas laisser perdre l'énergie utilisée pour les fabriquer, d'autant que leur pouvoir calorifique est pratiquement équivalent à celui des matières premières mises en œuvre. Cette énergie, qui est dans une certaine mesure « immobilisée » dans les produits en fin de vie, peut être exploitée via le recyclage des matières ou la valorisation énergétique, selon la forme et la qualité des déchets plastiques. En Europe, plus de 50 % des déchets plastiques sont valorisés d'une de ces façons. Dans neuf pays européens qui se sont dotés d'une bonne infrastructure de gestion des déchets, le taux de valorisation des déchets plastiques dépasse 80 %, mais dans la majorité des pays d'Europe, dont la Pologne et le Royaume-Uni, il est inférieur à 30 %.

Plus de 60 % des déchets plastiques proviennent d'emballages, qui représentent de loin la plus forte proportion de matières recyclées. Les procédés de recyclage des emballages sont perfectionnés d'un point de vue technique, et leur efficience écologique a été largement étudiée. A cet égard, les analyses du cycle de vie de HEYDE/KREMER (1999), par exemple, qui ont été consacrées aux différentes filières de valorisation des déchets d'emballages plastiques des ménages, ainsi que les nombreuses études complémentaires réalisées, ont joué un rôle fondamental.

En revanche, les possibilités de recycler et de valoriser les déchets plastiques des secteurs domestique et commercial qui ne proviennent pas d'emballages ont été moins étudiées et mises en valeur. Ces généralités jettent les bases de la synthèse des connaissances aujourd'hui disponibles concernant ce domaine, qui a été établie ici à partir d'une étude documentaire.

Objet de l’étude documentaire

Le présent examen se fonde essentiellement sur une étude commandée par l’Agence fédérale allemande pour l’environnement (UBA) et l’Association allemande des fabricants de plastique. Cette étude, remise en 2006, analyse les possibilités de recyclage des déchets plastiques autres que les déchets d’emballage, lesquels font l’objet d’une collecte séparée et d’une réglementation stricte. Sont concernés à la fois les plastiques que l’on trouve dans les déchets des ménages, par exemple dans les déchets résiduels et les encombrants, et les autres plastiques présents dans les déchets commerciaux. Dans le cadre de cette étude, à laquelle ont participé plusieurs instituts et qui se compose de sept sous-rapports, ces déchets particuliers ont été quantifiés, décrits et classés en catégories. Mais surtout, les possibilités de valorisation de ces déchets ont fait l’objet d’une analyse approfondie de leurs performances écologiques, ainsi que d’une évaluation économique. Pour permettre des vérifications et des corrections, les évaluations écologiques et environnementales reposent sur la norme internationale ISO 14040, et elles ont en outre été soumises à un examen critique réalisé par des spécialistes indépendants.

Vu qu’on dispose d’une masse de données relativement importante au sujet des effets des produits plastiques sur l’environnement durant l’ensemble de leur cycle de vie, les analyses des performances écologiques examinées ici se concentrent sur le stade de déchets, dans la mesure où des performances environnementales très variables correspondent aux diverses options de gestion des déchets. Cela étant, les analyses des performances écologiques se rapportent à des processus parfois très différents et complexes, de sorte que les résultats peuvent seulement fournir une orientation préliminaire, mais n’offrent pas un point de départ valable pour trancher des cas individuels. Pour permettre une meilleure classification des résultats, le présent document propose également une vue d’ensemble de la production, de la consommation et des quantités de déchets, en s’appuyant sur les données de l’année 2007.

Résultats

En définitive, l’analyse écologique des options de valorisation des déchets plastiques autres que les emballages n’a pas permis de mettre en évidence une solution globale pouvant s’appliquer à tous les types de déchets. Une chose est certaine et des études récentes l’ont d’ailleurs corroboré (comme celle réalisée en 2010 pour le compte de l’UBA sur les « possibilités de protection du climat offertes par la gestion des déchets ») : toutes les formes de valorisation sont préférables à la mise en décharge. En revanche, il n’existe pas de filière de valorisation supérieure aux autres. Au bout du compte, ce sont des critères comme l’origine du flux de déchets, sa qualité et la quantité qu’il représente qui déterminent la forme de valorisation optimale.

D’un point de vue purement écologique, le recyclage des matériaux présente dans certaines circonstances des avantages par rapport aux autres formes de réutilisation, si les déchets sont aisément identifiables et donc faciles à trier et s’il est possible de les collecter en quantités suffisantes sans engager des frais et des efforts importants. Dans ce cas, il est écologiquement rationnel de séparer la plus grande quantité possible de déchets plastiques des déchets ménagers en vue de réutiliser les matériaux. Parmi les exemples typiques, il y a les bouteilles en PET et les films polyoléfines qui sont triés afin d’être recyclés. En outre, il faut qu’il existe des marchés pour les produits issus du processus de recyclage, c’est-à-dire des marchés des produits en plastique recyclé.

La situation est similaire en ce qui concerne les déchets volumineux et commerciaux. Si les plastiques peuvent être triés par type pour un coût modique en faisant peu d’efforts, le recyclage des matières est avantageux sur le plan écologique. En revanche, s’il n’est pas possible d’assurer un recyclage techniquement ou économiquement efficient, par exemple en présence de déchets mélangés ou contaminés, la valorisation énergétique constitue la meilleure solution. En particulier, si l’on prend également en compte les aspects économiques, la valorisation énergétique, voire dans certains cas le recours à des procédés de valorisation qui mettent à profit les propriétés des matières premières, tels que l'utilisation comme agent réducteur dans des hauts fourneaux, sont tout aussi valables ou même supérieurs.

En conclusion, on peut avancer qu'en principe, une gestion efficiente des déchets consiste à optimiser le dosage des différents procédés de valorisation. Les contraintes locales sont alors déterminantes: structures de collecte des communes ou des entreprises privées, qualité et rendement des déchets, et – aspect primordial – possibilités de commercialiser les produits issus de la valorisation, qu'il s'agisse de matières recyclées, de produits chimiques de base ou d'énergie.

GLOSSARY OF ACRONYMS

ABS	acrylonitrile butadiene styrene co-polymer
ASA	acrylonitrile styrene acrylate co-polymer
BMU	Federal Ministry for the Environment, Nature Conversation and Nuclear Safety, Germany
BDE	Federation of the German Waste, Water and Raw Materials Management Industry, Industrial and Employers' Association
EPS	expandable polystyrene
LCA	Life Cycle Assessment
MSWI	Municipal solid waste incineration
PA	polyamide
PE	polyethylene
PE-HD	polyethylene high density
PE-LD	polyethylene low density
PET	polyethylene terephthalate
PMMA	polymethylmethacrylate
PP	polypropylene
PS	polystyrene
PUR	polyurethane
PVC	polyvinyl chloride
SAN	styrene acrylonitrile co-polymer
UBA	Federal Environment Agency, Germany
UFOPLAN	Environmental Development and Research Programme

I - INTRODUCTION

1. Plastics production and consumption has been rising continuously for many years, as has the amount of plastic waste, which is increasingly recognised not as waste, but as a resource for manufacturing new products or generating energy. On average, around half of the plastic waste arising in Europe is already recovered, while the other half is generally still disposed of in landfills without any further use. However, plastic disposal in landfills and plastic recovery varies from country to country in Europe. In countries achieving a high recovery rate, bans on landfilling wastes with a high calorific value have proved a decisive incentive. The recovery of packaging waste, in particular, has reached high levels in a number of European countries. In other areas of plastics use, further potential remains both in the commercial sector and in the private household sector.

2. As early as 1999 the German Federal Environment Agency and the German association of plastics manufacturers (Verband der Kunststofferzeugenden Industrie), which now operates under the name PlasticsEurope Deutschland e.V., set up a joint study within the environmental research programme "UFOPLAN" to identify this potential for Germany. Several organisations contributed to the study, which eventually categorised non-packaging plastic waste in seven sub-reports, quantified it and subjected its recovery to both environmental and economic evaluations. Of particular interest at this point is the extensive environmental life-cycle assessment (LCA). With reference to this, the authors of the critical review to which the joint study was submitted pointed out that, in view of the many different processes, the identification and environmental assessment of the recovery potential of plastics from the commercial sector and residual households is an extremely complex and difficult task. In this study finally, dozens of LCAs and hundreds of sub-processes were brought together in the seven sub-reports. The manner in which the study was performed and its results presented shows that more of a scoping LCA was carried out, and that while the results highlight tendencies and have a model character, they are not directly appropriate for deciding specific measures for individual cases (the authors of the study themselves emphasised this limitation).

3. The presentation of the LCA results, which are now compared with data available from 2007, serves as such a scoping assessment. The example of Germany is used to characterise the quantities of waste and their provenance, both because the LCA studies relate to German waste and because of the availability of comprehensive recent data for 2007. However, the global and European situation regarding plastics manufacture, consumption and recycling is first set out in more detail.

II - SCOPE AND OBJECTIVES

4. Plastics are produced in an enormous variety of different polymer substances, which are in addition compounded to design them for their often special use. Therefore, it is nearly impossible to describe the environmental impact of all plastics, concerning their manufacture as well as availability of data. Furthermore only in rare cases (for example production residues or PET bottles) the recycled plastic is destined for the same purpose as before or as the same plastic (PET to PET). In most cases mixtures of plastics (*e.g.* PE/PP mixtures) are processed into a re-granulate which then can be used for different purposes than the plastics have been used before. This leads to the result, that the ecological performance analyses of a LCA relates to sometimes very different and complex processes so that the results can only form an initial orientation, but not a valid basis for taking decisions in individual cases. For a better classification of the results the present paper also gives an overview of the production, consumption and waste quantities, whereby the data relates to the year 2007.

5. The present document cannot, and is not intended to replace the chemical textbooks or the "Reference Document on Best Available Techniques about the Production of Polymers". Indeed, it gives general guidance for an ecologically and economically efficient management of complex waste streams taking the example of Germany into account. The results show a significant contribution to resources savings by waste recovery either as material or energy under an appropriate divert-from-landfill implementation. To achieve this goal, an efficient interplay of concerned stakeholders is necessary, *i.e.* politics and administration with authorities, municipalities, industry and the consumer.

6. The scope was to analyse the recycling potential of plastic waste other than the separately collected packaging, which is largely regulated. This relates both to plastics in private household waste, for example, in residual waste and bulky waste collections, and to other plastics in commercial waste. As part of the study, in which several institutes participated and which is made up of seven sub-reports, these types of special waste were quantified, their nature described and categorised. But above all, possible options for recovering this waste underwent a comprehensive ecological performance analysis and were also economically evaluated. For the purpose of verification and correction, the ecological and environmental assessments are based on the international standard ISO 14040 and, additionally, a critical review by independent peers has been performed.

III - PLASTICS PRODUCTION AND CONSUMPTION

7. Continuous innovation has made possible a global average annual rise in plastics manufacture and consumption by about 9% since 1950. Global plastics production rose from approximately 1.5 million tonnes in 1950 to 260 million tonnes in 2007. An analysis of the plastics consumption per capita shows that this has now risen to around 100 kg per inhabitant in the NAFTA (North American Free Trade Agreement) countries and Western Europe, and has the potential to grow to 140 kg per person by 2015. The greatest potential for growth is in the fast developing parts of Asia, where present per capita consumption is rather low, about 20 kg per capita (except in Japan). In Europe, the greatest potential for growth resides in the new European Union Member States. Their current consumption is between 50 and 55 kg per capita on average, and thus just over half the consumption in the old European member states. Nevertheless, the global economical crisis has impacted the plastics industry and its value chain significantly.

1. Plastics Production and Consumption in Europe

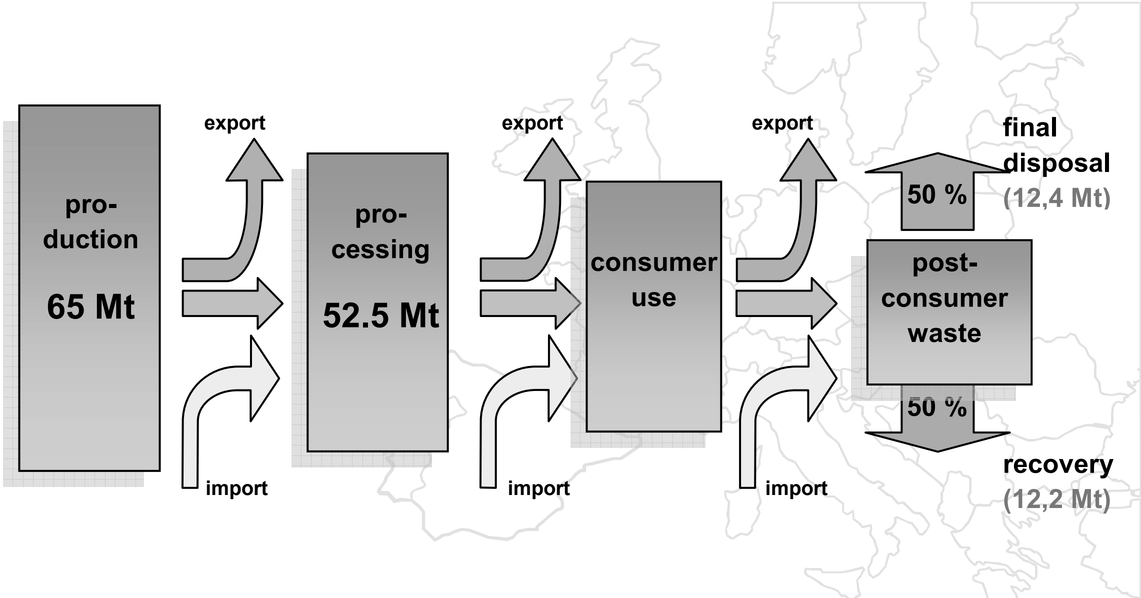
8. The EU27 countries together with Norway and Switzerland are the source of 65 million tonnes of plastics production per year, which represents 25% of global production, even more than the 23% produced by the NAFTA countries. Within Europe, Germany is the largest producer with a 32% share, followed by the Benelux countries (18%), France (12%), Italy (8%) and the United Kingdom and Spain (6% each). In 2007, the processors' demand for plastics in the EU27 + Norway and Switzerland amounted to 52.5 million tonnes. The highest demand comes from Germany and Italy, which together account for 40% of European consumption. Of the new member states Poland has the largest share with 2.35 million tonnes. The Czech Republic and Hungary each consume about half this volume. Processing of plastics in the new member states is expected to rise further in the coming years.

9. There are around twenty large groups of plastics, each with numerous subgroups, which allow optimal selection of a specific plastic for each application. Five groups dominate in terms of production volumes. These are polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polystyrene (rigid PS and expanded/expandable EPS) and polyethylene terephthalate (PET). Together, these five make up 75% of the total demand for plastics in Europe. In the course of 2007 all the plastics listed above recorded an increase in demand of between 0.5 and 7.5%, with an average of 3%. The packaging industry remains the largest end user for plastic materials, with 37%, followed by the construction industry with 21%. The automotive and electrical/electronic sectors consume 8% and 6% of the total volume respectively. Medical technology, the leisure sector and other application sectors such as household and agriculture account altogether for the remaining 28%.

2. Half of all Plastic Waste is recovered

10. Figure 1 shows the whole plastics value chain from production to end-of-life. The data relates to the EU27 countries plus Norway and Switzerland. In 2007, demand from processors amounted to 52.5 million tonnes of plastics, an increase of 3% over 2006. Taking foreign trade into account, 47 million tonnes were processed in Europe.

Figure 1: Plastics value chain from production to end-of-life in 2007 (EU27+ Switzerland and Norway



11. Out of all plastics used by consumers, 24.6 million tonnes ended up in the corresponding post-consumer waste streams, compared with 23.7 million tonnes in 2006. Fifty percent of the plastics from household wastes were recovered and another 50% were disposed of to landfill.

12. About 5 million tonnes were recycled and via feedstock operations and 7.2 million tonnes used for energy recovery. The total rate of material recovery, *i.e.* recycling of plastic waste stood at 20.4% in 2007, of which 20.1% was material (up 1.2 percentage points from 2006) and 0.3% feedstock (down 0.3 percentage points from 2006). The energy recovery rate remained stable at 29.2%, reflecting how sensitivity and planning complexity surrounding this technology can only lead to slow progress. In 2007, 12.4 million tonnes of plastics were disposed of in landfills.

13. Despite an annual increase of 3% in plastic waste generation over the last decade, the amount of landfilled waste remained unchanged. The increase in plastic waste is the result of several factors. Plastics make a considerable contribution to innovative products. Economic growth results in higher consumption, smaller households require more packaging per person, and more individual ready-made meals are consumed as a result of the change in population structure.

14. There was a further increase of 1% in the volume of mechanical recycling in 2007, which can be explained by higher plastic prices and improved collection and sorting technologies. The growth of energy recovery slowed to 3%, as little capacity was added in 2007. Greater investment is needed here, in order to channel streams that cannot be materially recycled in an eco-efficient manner into energy recovery processes, thus diverting plastics from landfilling.

3. A Landfill Ban is a Major Incentive

15. Material and energy recovery of plastic waste varies widely from country to country. In some countries, such as Switzerland, Germany, Sweden and Denmark, landfilling of plastics is restricted; these countries have achieved or are very close to reaching their target of diverting organic waste from landfilling. A recently published study by the Swiss consultancy firm Prognos shows that 27% of greenhouse gas emissions could be prevented, if all waste currently disposed of in European landfill sites were redirected for recycling and energy recovery. The best results were achieved without pre-determined routes for waste recovery. Moreover, employing complete flexibility helped in using the best possible solution for each waste stream, whether through material or energy recovery.

16. A careless throw-away into the landscape, so called littering, should be forbidden, and instead, waste should be submitted to eco-efficient management. Diverting from the landfill would result in reduced greenhouse gas emissions and in improved resource efficiency.

17. An important observation is that countries with high recycling rates are successful in both material recycling and energy recovery. Therefore, a waste strategy which includes energy recovery does not run counter to achieving good results also in material recovery, but rather supports this. It appears that a coherent strategy of resource management must address both of these, as no country can recycle all its waste purely through material recovery.

18. Whereas material recovery rates are relatively similar in most EU27 countries plus Norway and Switzerland, there are major differences in the use of energy recovery. Countries which currently make extensive use of landfill will in future not only have to tap their whole recycling potential, but will also have to undertake a rapid expansion of their waste-to-energy system. The phase-out of landfilling is generally a slow process, with a rise in recycling rates (material and feedstock) from 19.5% in 2006 to 20.4% in 2007 in the EU27 plus Norway and Switzerland, while energy recovery remained unchanged at 29.2%.

19. In many member states of the EU it will require major efforts to exploit the full potential offered by the strategy to abolish landfill – a potential that encompasses reduced greenhouse gas emissions, improved resource efficiency, greater energy security and the avoidance of enforced sanctions, such as in the case of illegal transboundary shipment when landfilled elsewhere.

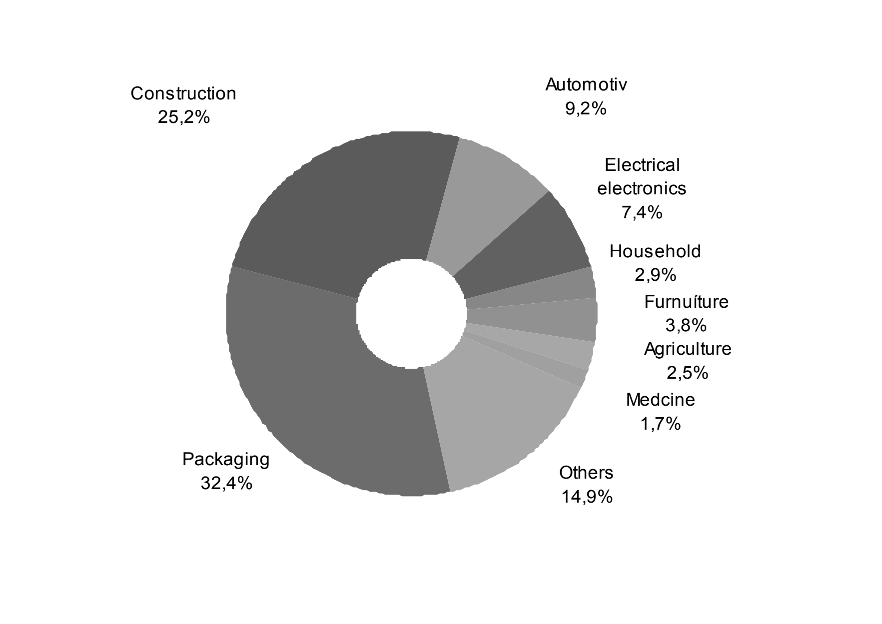
4. Plastics Production and Use in Germany and Resources Consideration

20. The diverse sources of plastics waste will be shown using Germany as an example, which occupies a leading position in Europe in both plastics production and consumption and has extensive statistical material available.

21. In 2007, the quantity of processed plastics in Germany amounted to around 12.5 million tonnes. The application sectors packaging and building/construction in particular, but also engineering applications in the automotive and electrical/electronic sectors, are still the main areas of plastics use, as shown in Figure 2.

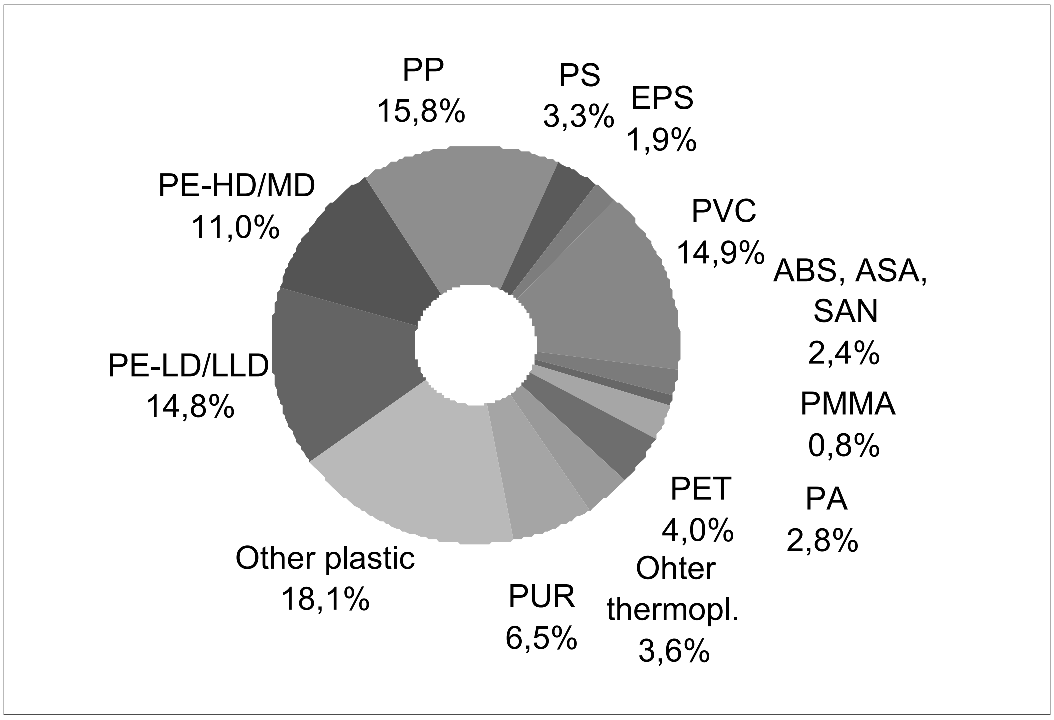
22. Of the processed plastics, the most represented types are polyolefines (polyethylene and polypropylene) and PVC, with a share of over 57%. Apart from that, PVC continues to enjoy a high degree of acceptance, especially in the construction sector.

Figure 2: Distribution of processed plastics by sector in Germany, 2007



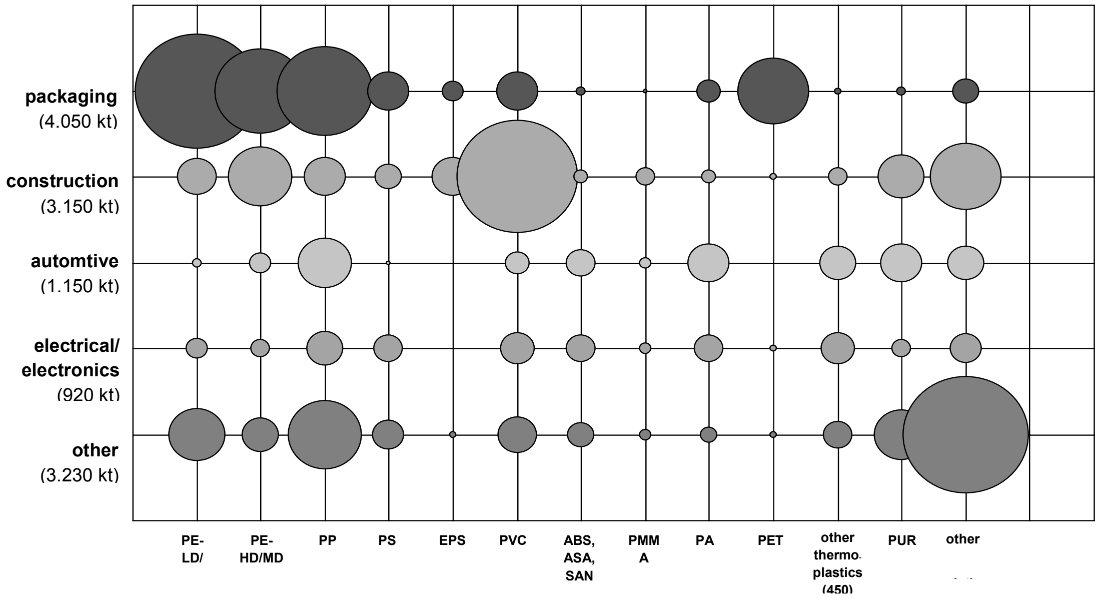
23. Compared with previous years, the strongest growth rates are recorded in PUR and EPS on account of increased demand for building insulation, in ABS, ASA and SAN in engineering applications, and in other mostly engineering thermoplastics, especially in automotive and electrical/electronics applications. The demand of processed plastics types is shown in Figure 3.

Figure 3: Proportion of each plastic type processed in Germany in 2007



24. Figure 4 shows the proportion of each plastic type in the individual application sectors. The size of the spheres correlates with the consumption of the corresponding plastic type.

Figure 4: Plastics processing; proportion of plastic types used in the packaging, construction, automotive, electrical/electronic and other industries in Germany in 2007



25. Why is this manifoldness of plastic types in the diverse application sectors observed? Plastics are designed to serve an optimum performance during their use in all the many diverse applications and products. Owing to their multi-purpose character, which is perfectly adapted to today's techniques, plastics are an ideal material for the construction of final products in the diverse application fields. You can find them in mobile phones as well as windows and they make up all sorts of appliances from packaging to automotive.

26. Plastics also help reducing energy consumption during use. They insulate refrigerators and freezers, thereby contributing to high energy efficiency. Furthermore, polymers are highly appreciated for the transparency and resistance, their stiffness as well as flexibility. Plastic materials provide maximum freedom during the design phase of an appliance and contribute to the continuous miniaturisation of modern technologies such as in the information and telecommunication sector.

27. Of utmost importance is the fact that the price/performance-ratio of final products, which are put on the market, is getting better every day. Plastics and their highly resource-efficient processing methods make a big contribution to this.

28. Often, plastic components are made from blends of different compatible polymer types – the so called polymer blends. In order to achieve tailor-made properties in this way, *e.g.* through moulding, components becomes stiffer and at the same time even more impact and heat resistant.

29. In Western Europe, around 80% of mineral oil is solely used as diesel or petrol in vehicles, in heating systems or for electricity generation. In other words, 8 out of 10 litres of oil are burned directly. Only around 4 – 6% of mineral oil and gas is used in the manufacture of the wide range of plastics and a large share of these actually help us to reduce the use of oil for energy purposes, *e.g.* by reducing fuel consumption of cars, by decreasing the overweight of the vehicle or by considerably reducing the energy

required for heating as a result of effective insulation of buildings. It is clear that transport and heating are the biggest consumers of energy, but to reduce the consumption of energy overall, it is also important to understand in what phase of a product's life-cycle most energy is consumed. This enables a targeted approach for the development of saving options. Today, we understand that by far the largest volumes of primary resources are consumed during the use phase of products, on average 80% of total energy consumption.

30. This is demonstrated well in large domestic appliances for which very precise figures are available: Here, energy consumption during the use phase is 90%, while 9,8% are used for manufacture and 0,2% for managing the end-of-life stage. Therefore, it is easy to see that reducing energy demand during the use phase is of particular importance: The less electricity a TV set requires, or the less water a washing machine consumes, the better, not only for the consumer's purse but also for the environment. Furthermore, new and more energy efficient products also improve industry competitiveness.

IV - AN OVERVIEW OF PLASTIC WASTE

31. On average, around 50% of plastic waste is recovered in Europe. However, there are big differences between individual countries. High recovery rates are particularly evident in countries where landfilling of high calorific waste is largely restricted or totally banned. The dominant compounds within the plastic waste streams from the post-consumer sector, which are especially suitable for material recycling, are from the packaging area, as shown in Figure 5. The potential for the recovery of other types of plastic waste has been limited. Therefore the German Federal Environment Agency (UBA) and PlasticsEurope Deutschland e.V. have jointly commissioned a scoping study to identify the quantities arising and possible recovery paths for plastic waste previously sent to landfill in Germany. The packaging sector was to be excluded from this specific study. The research, which took place in several stages and was completed in 2006, is based on data collected in 1999. With the addition of up-to-date figures available for 2007, the following environmental and economic assessment emerges, providing a starting point for further work on the subject:

32. From the environmental perspective, the best course of action is material recycling of those clearly identifiable and clean plastic wastes from the commercial sector and private households which can be easily separated. The requirement is that the recyclables recovered in this way substitute virgin plastic material in the ratio of 1:1 or close to 1:1. Where this is not possible, feedstock recycling or energy recovery would be the next best solution.

33. From the economic perspective, all recovery paths are more expensive (at the time of the study) than landfilling or incineration (without energy recovery) of plastic waste.

34. When taking into account both environmental and economic considerations the following general observations can be made:

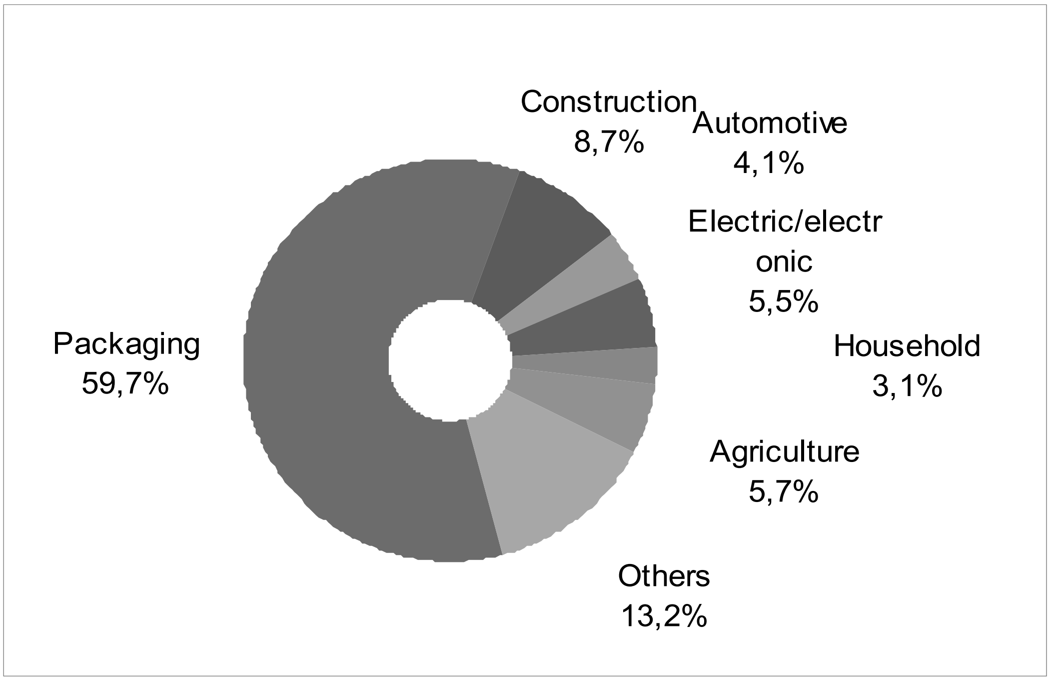
- For discarded plastics that can easily be collected in homogeneous fractions, such as plastic pipes, material recycling appears to be the best solution and is already being carried out to some degree.
- For the bulk of mixed and contaminated plastic waste, large-scale feedstock recycling or energy recovery processes are suitable options.
- The factors governing the individual case determine what is the most environmentally sound and most economic – *i.e.* most eco-efficient – recovery mix. These factors include collection yields, the way in which sorting residues are managed, the substitution factor and the commercial viability of the recycled and recovered products.

1. Management of Plastic Waste

35. In the society, at some point every product becomes to an end of its useful life. Consequently, end-of-life appliances or other products have to be treated and finally disposed of. Plastics are just one out of many materials which consumers discard.

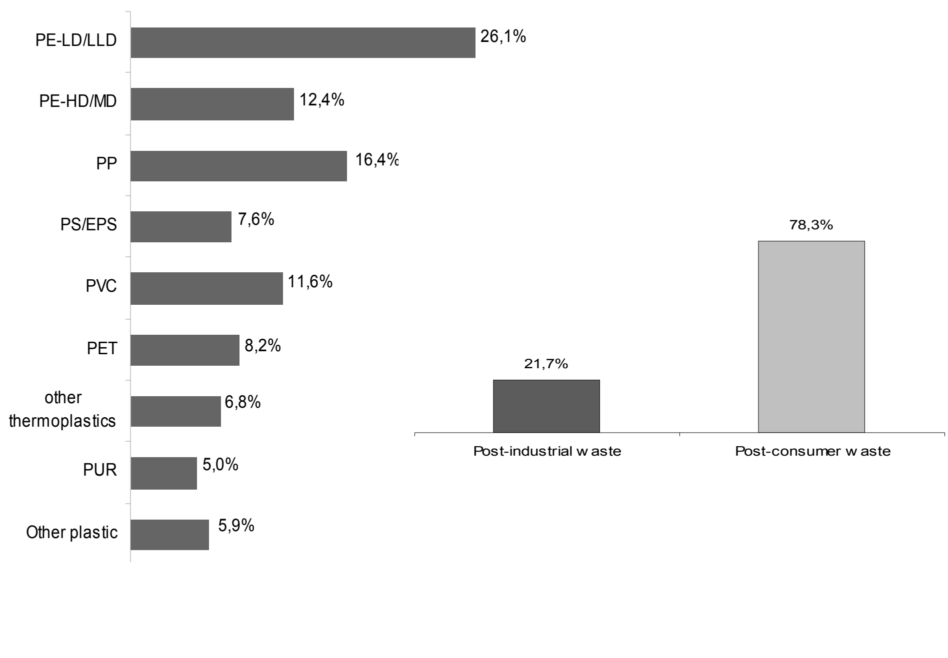
36. With respect to the plastic waste fraction only, the German plastic waste amounted to a total of 4.86 million tonnes in 2007. This quantity is made up of 1.05 million tonnes of waste from the industrial and commercial sector, and 3.81 million tonnes of post-consumer plastic waste from the household sector.

Figure 5: Proportion of post-consumer waste by sector, 2007



37. PE-LD und PE-LLD dominate in the analysis of the plastic types, corresponding to the high proportion of packaging in plastic waste.

Figure 6: Distribution of plastics types in total waste plastics

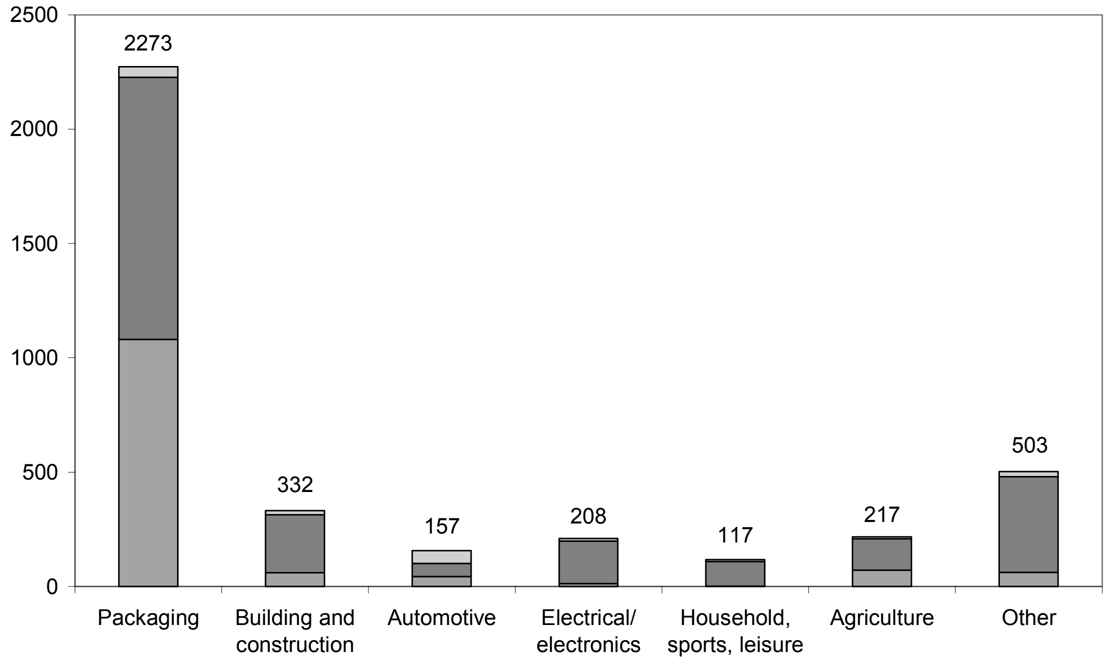


38. Owing largely to the ban on landfilling waste with a high calorific value that came into force in Germany on 1 June 2005, a recovery ratio of almost 96% was reached in 2007.

39. Due to high quality of post-industrial waste, the majority of this waste is recycled (80% out of 99% recovery). This is not the case for the soiled and mixed different waste streams from households and post-consumer sectors. Around 95% recovery of post-consumer waste was achieved in Germany, of which 1/3 was recycled. Packaging dominates increasing post-consumer waste amounts, comparable to the construction and agricultural sectors. The increasing quantities of packaging from households and agriculture are rapidly becoming waste, the growing waste amounts in the construction sector are mainly consisting of returnable durable products such as windows, pipes and profiles.

40. A total of 35% was recovered by material recycling (1.300 kt), of which 33% was through material recycling and 2% through feedstock recycling. Based on the definition quoted, 60.5% was consigned to energy recovery (2.310 kt), so that ultimately only 4.5% (170 kt) was disposed of in landfills. In Germany, more than 80% of material recycling is based on the management of used packaging (1.080 kt). The bulk of this consists of packaging from households, which is generally collected via the "Duales System Deutschland", DSD, *i.e.* the collection of light weight packaging waste (consisting of plastics, paper, components, etc.), alongside the normal municipal waste collection and sent for recovery as well as for recycling of PET bottles[1]. The amounts recovered according to the application sector are shown in Figure 7.

Figure 7: Amounts of recovered plastic waste by application (in kt)

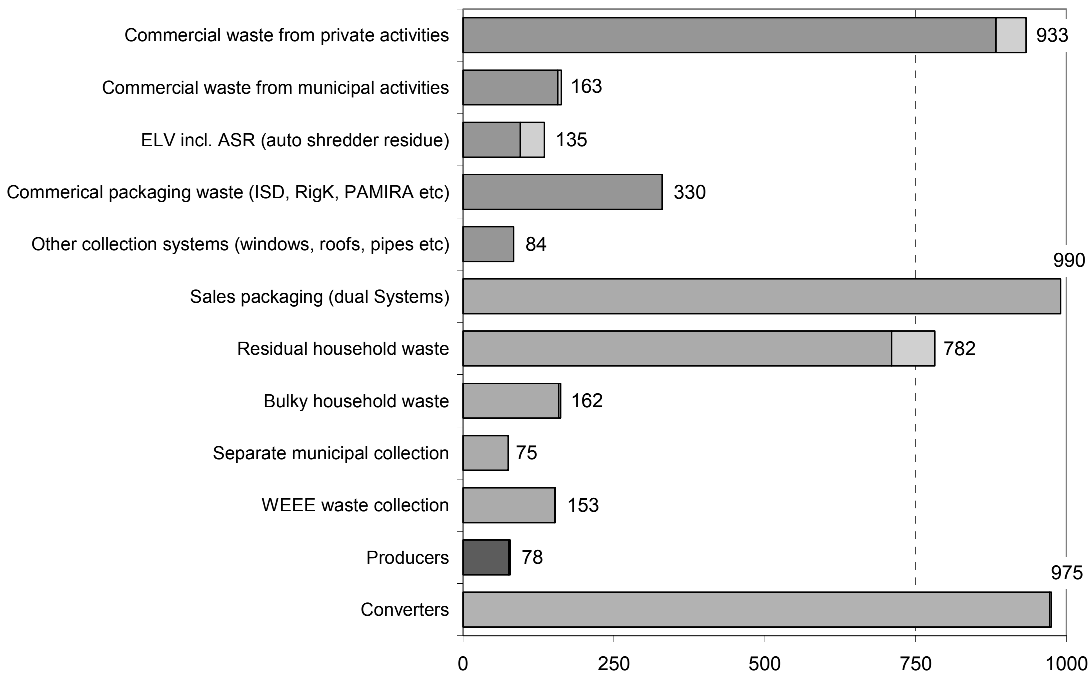


Blue bars: material recovery (recycling); green bars: energy recovery; grey bars: landfill

1 Today, for managing packaging waste in Germany nine dual systems are in place, where the DSD represents one of the most important systems

41. Figure 8 shows the quantities arising from each source and the extent to which these are recovered or disposed of in the landfill.

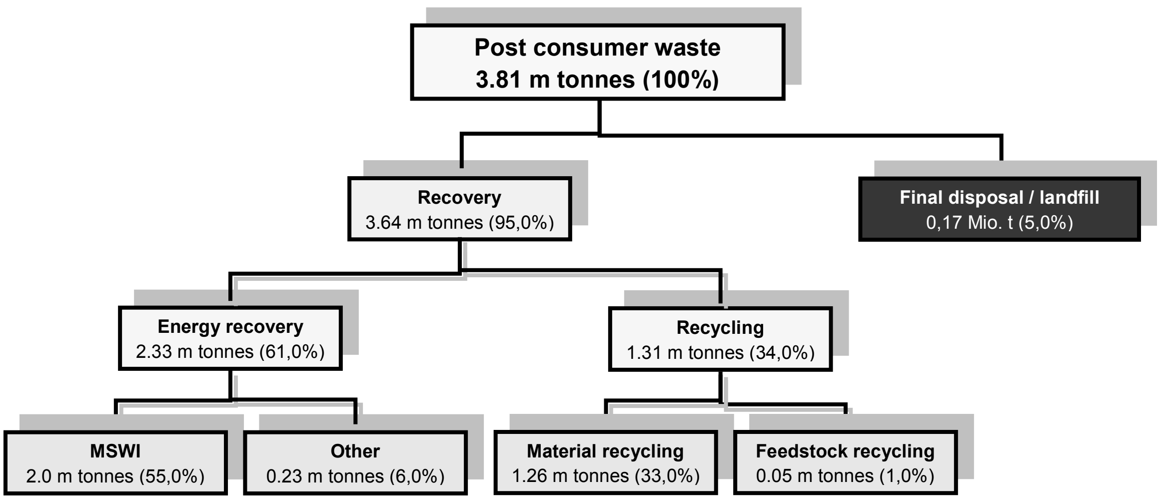
Figure 8: Plastic waste recovery and landfill by origin (in kt)



Grey bars: commercial end-users; blue bars: private end-users (households); green bars: post-industrial waste; bold face colour: recovery; grey light colour: landfill

42. An overview of the recovery of post-consumer waste is shown in Figure 9.

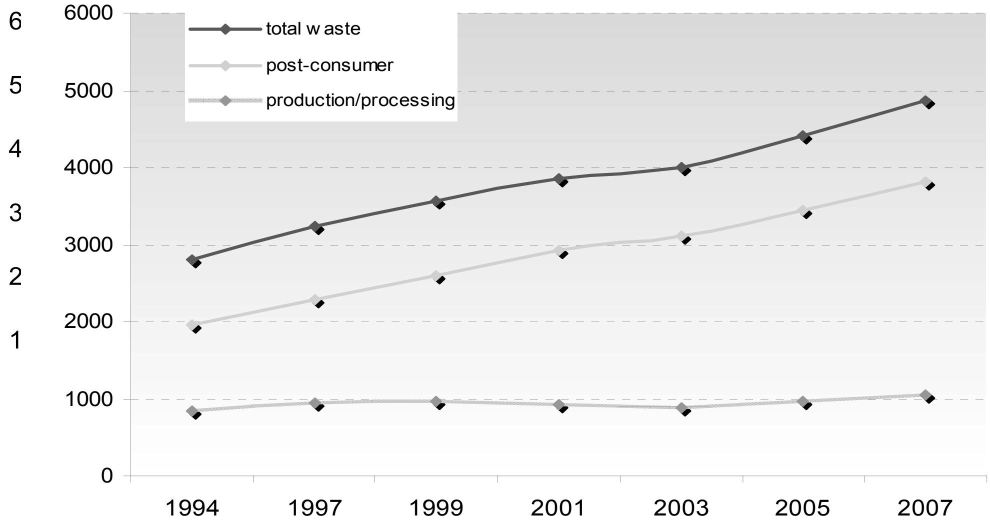
Figure 9: Recovery of post-consumer waste in Germany 2007



43. Examination of the expansion in total plastic waste over the period from 1994 to 2007 reveals a rise of around 2 million tonnes or 4.3% per annum in Germany. This can mainly be traced back to post-consumer waste, which rose by more than 95% alone, or 5.3%/a. Manufacturing and processing waste, however,

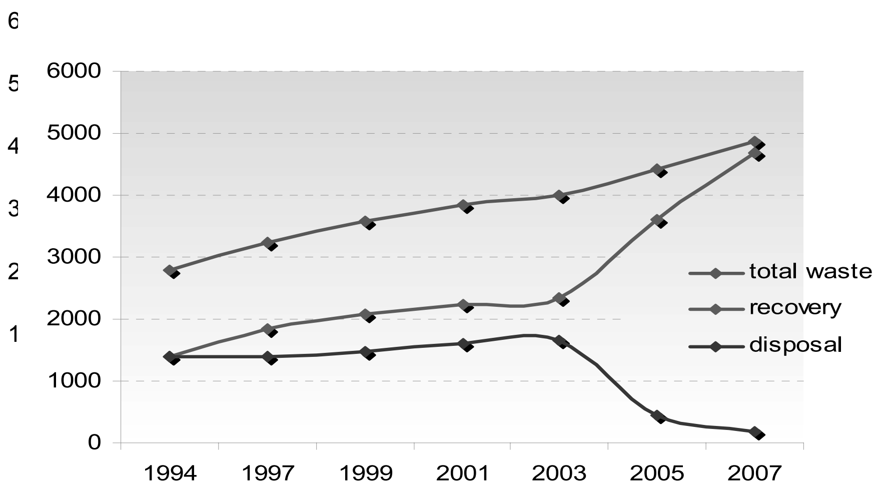
increased only slightly, despite significantly higher outputs, owing to improved production and processing methods: in total by 24% or 1.6%/a.

Figure 10: Development of post-consumer plastics waste and post-industrial plastics waste quantities (in kt)



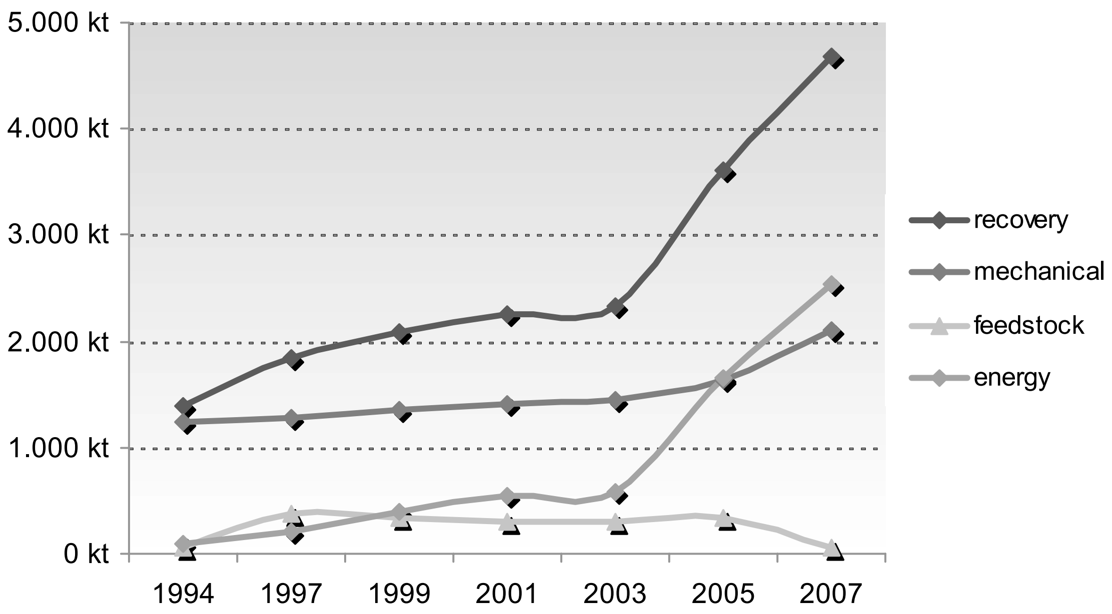
44. Quantities recovered, *i.e.* diverted from landfill, have also increased significantly. They rose from 1400 kt in 1994 to 4680 kt in 2007. The amount of landfilled waste fell to 180 kt in 2007, from 1400 kt in 1994. In the same period, recovery rates rose from 50% to approximately 96%. Whereas today almost 100% of post-industrial waste*, i.e.* waste from production and conversion, is recovered; the figure for post-consumer waste stands at around 95%. As shown in Figure 11, the plastics industry's efforts towards a "diversion from landfill" strategy in Germany have been very successful.

Figure 11: Quantities of waste going to recovery and disposal



45. At present, material recycling stands for 2.1 million tonnes, which is about 850,000 tonnes, or 70% more than in 1994. Compared with 2005 the figure rose by 470,000 tonnes. The average annual increase from 1994 to 2007 was 4.1%. Feedstock recycling, which rose sharply at the beginning of the decade and after that remained constant at around 300,000 tonnes, stood at about 70,000 tonnes in 2007. The largest and most steady increases took place in energy recovery in efficient waste incineration plants (MSWI, heat power plants and cement kilns). This amount has increased from 100,000 tonnes in 1994 to over 2.5 million tonnes in 2007. The growth since 2005 can however be attributed in part to the rigorous implementation of the European Union waste legislation (recognition of energy-efficient incineration plants), as well as the implementation of the German landfill regulation (Deponieverordnung) which stipulates a landfill ban from mid 2005 on. The development of the recovery pathways is shown in Figure 12.

Figure 12: Expansion of waste recovery (in kt)



V - RECOVERY OPTIONS

46. For plastic waste from end-of-life products, there are in principle the following three possibilities for waste management by recovery:

- **Material recycling** is the mechanical preparation of used plastics into regrind or recyclables that can be readily reprocessed. The chemical structure remains nearly unchanged. The discarded items are shredded, cleaned and sorted into categories. Material recycling is viable when discarded items are clean and sorted according to type, or can easily be cleaned and sorted.
- **Feedstock recycling** is the splitting of plastics into smaller particles by means of heat or chemical reaction. Mainly this method produces oils or gases from which new plastics or other chemical resources can be manufactured. Feedstock recycling is appropriate for mixed or contaminated plastics.
- **Energy recovery** is the incineration of plastic waste, while at the same time using the energy to generate electricity and/or steam, or to provide process heat. Energy recovery is especially appropriate for mixed, contaminated or degraded plastic wastes.

47. As the study within the environmental research programme has shown, the quality of each type of waste is critical in deciding the appropriate recovery option. Therefore, as part of the research, the wastes identified are first classified by defined qualities. They can be assigned to the following three categories:

1. Clean and soiled, but unmixed plastics;
2. Clean and soiled mixed plastics, including composite materials (usually packaging);
3. Plastics with foreign material.

48. Unmixed plastic fractions mainly originate from segregated collections in the commercial and industrial sectors. This applies to around 14% of the wastes investigated. Wastes in the second category mostly come from private households (around 70%). The lowest quality plastics are found in household collections of discarded electrical appliances, which contain a wide variety of materials and, consequently, recovery possibilities (around 16%) are most limited.

1. Suitable for Material Recycling

49. The requirement for material recycling is that the discarded plastics are separately collected. Therefore, it is necessary to identify the different types within the total quantity of discarded plastics and collect them separately. In this context the following types are considered suitable for material recycling – regardless of whether there is market for the resulting recycled materials:

1. Pipes made of PVC or polyolefines from bulky waste collection and from the commercial sector;
2. Mattresses and upholstery from bulky waste collection;
3. Mulch film from agriculture;

4. Unbrominated plastic housings used in the electrical/electronics sector[2];
5. PUR seat upholstery from end-of-life vehicles;
6. Plastic films from the building and construction sector;
7. Waste cables.

50. Plastic waste is not suitable for material recycling, when it is contaminated, its composition is too varied or the quantity is not above a critical mass.

2. Feedstock Recycling and Energy Recovery

51. Feedstock recycling processes, such as syngas production, blast furnace technology or utilisation as secondary fuel, are appropriate for all qualities, as long as certain specifications are met.

52. The following types of plastic wastes can be recovered in this way:

- Plastics from residual waste (separated as mixed plastic waste);
- Plastics from bulky waste (separate collection containers at bring-systems);
- Plastic waste from the so called “yellow bin”, *i.e.* local recycling bin (including discarded electronic equipment) collected by public sector waste management entities (separate collection);
- Plastics from shredding operations.

[2] The identification of non brominated components is not state-of-the-art technology and can therefore at best be tested in a separate pilot project.

VI - ENVIRONMENTAL ASSESSMENT

53. In the context of the study, the recovery options and classifications of the plastic waste streams were subjected to a comparative life-cycle assessment (LCA). The purpose was to identify the best environmentally sound recovery solutions. The LCA was carried out according to ISO 14040 and 14044, as well as according to the German Federal Environment Agency's LCA rules and was submitted to an in-process critical stakeholder review in accordance with ISO 14040, Section 7.3.3.

54. Each recovery system was examined by the LCAs, from collection through preparation to recovery:

- Material recycling: substitution of primary plastics (substitution factor close to 1);
- Feedstock recycling (blast furnace, syngas production);
- Energy recovery (cement kiln, municipal solid waste incineration (MSWI))

55. Mass-specific life-cycle inventories and impact assessments were carried out for the selected recovery systems. The impact categories are: global warming potential, waste generation (as an indicator of natural land use), eutrophication potential (terrestrial and aquatic), acidification potential, crude oil equivalent and primary energy demand. Owing to the data available, not all aspects relevant to the environment could have been taken into account.[3] Credits were assigned for the products of the recovery process, such as recyclables or electricity, taking the substitution potential into account.

56. Finally the effects were identified and compared with the reference system: "Treatment in an average waste incineration plant". The incineration plant with this average state-of-the-art technology, when the study was performed, was the sole reference system for all the recovery paths examined.

57. The following sources and plastic wastes were specifically assessed by the LCA:

Residual household waste:	all plastic wastes
Commercial waste similar to household waste	all plastic wastes
Bulky household waste	PUR mattresses and upholstery
Commercial waste via private waste collection entities	all plastic wastes pipes (PVC und polyolefines) cable waste unbrominated electrical/electronic housings
Shredder operations:	all plastic wastes PUR seats from end-of-life vehicles

58. The aim of the sub-study "Environmental examination of potential recovery paths for plastic wastes from commerce and private households outside the Dual System" was to determine from an environmental perspective the best management path in each case for a range of potentially recoverable quantities and

3 For more detail see chapter below "Observations on the choice and determination of criteria".

sources. This is based on the requirements of the German waste law (Art. 6 para 1 of the German Closed Substance Cycle and Waste Management Act, KrW/AbfG[4]). The choice of sectors and areas was taken on the basis of the significance of the quantities and the expected recoverability of waste arising in each area, taking into account the degree of separation. Only plastic wastes from private and commercial end-users were investigated, as until that time these have not been recovered to a satisfactory extent and have for the most part been disposed of in landfills or incinerated without energy recovery.

59. The consideration of the plastic waste streams and management options was mainly undertaken in other sub-projects of the research programme. The stipulation of the management systems has a major influence on the evidence about the environmental advantages. The consequences of these stipulations are set out below in the diverse scenarios and sensitivity considerations.

1. Scenarios for Material Recycling

60. For material recycling, only the target product, *i.e.* the recyclate, is examined by looking at the substitution of primary plastics in the ratio 1:1 (substitution factor S = 1 or close to 1). In practice, specific product requirements can make substitution ratios of <1 necessary, which means that the specific material consumption is higher for the secondary than for the primary material. In such instances material recycling would lead to poorer results than would occur based on the assumptions made here. Moreover, in practice material recycling of plastic packaging waste is to a large extent targeted towards making moulded articles such as flowery pots, clothes hanger, cable channels or wheel housings in cars, which replace not only plastics, but also other materials such as wood, ceramics and concrete.

61. According to the analysis above, discarded plastics from households are assumed to be collected together with other waste via the DSD (Duales System Deutschland). A combined collection has the inevitable consequence that all the downstream stages of waste management, especially pre-treatment and recovery no longer differ anymore. Therefore the situation regarding material recycling of packaging, at least for mixed household plastics, needs to be described.

62. As a result of the introduction of updated sorting technology for packaging waste, which is also spreading to all other applications, the amount that can be used as a resource for material recycling to substitute for primary plastics has increased. With this sorting technology there will also be a sorting residue of mixed plastics which are not only suitable for material recycling, but which can also be used for feedstock recycling or energy recovery. Owing to the material specifications the distribution of plastics recycled from engineering applications such as automotive and electronic need not be identical to that from plastics packaging.

63. In many respects, material recycling of plastic waste has environmental advantages compared with energy recovery or feedstock recycling. For this reason the outcome of the analysis of the material recycling option is burdened by the stipulation of the waste management system, according to which, contrary to waste industry practice, mixed plastics is not regarded as a sorting category.

2. Scenarios for Energy Use

64. According to the study, the analysis of energy use is limited to its deployment in cement kilns and waste incineration plants. Recovery in power stations which, after converting the waste to secondary fuel, is in some cases also a practice applied in waste management, but is not considered here.

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4 This para states that in principle waste can be consigned to material or energy recovery. In addition, it introduces the criterion of the “more environmentally sustainable method of recovery”.

65. As part of future studies it might be useful to include energy recovery in power stations in the LCA; precisely these power stations combine the specific advantages of high utilisation of the energy potential of organic waste with appropriate flue gas purification. Therefore, these facilities can in certain respects demonstrate clear advantages over both waste incineration with low energy efficiency and recovery in cement kilns with respect to air pollution. As far as technically feasible, the aim in the case of high quality waste streams is in principle material recycling, because of the more favourable revenues in the market. Any remaining waste type, provided that it is appropriately pre-treatment and specified, is preferably used for feedstock recycling or energy recovery. Consignment to final disposal, *i.e.* landfill or incineration without recovery of the energy, is regarded as the very last resort.

3. The Influence of Resource Yields

66. The inventory analysis and impact assessment always relate to complete waste management systems, which alongside an examination of each recovery option are always linked with the management of the residues at a waste combustion plant. The yields related to the amounts of recovered waste vary widely, both between the individual types of waste and between the different management options of individual waste types.

67. In complete waste management systems, it is difficult to recognise the basic strengths and weaknesses of individual recovery options. Evidence concerning the resulting environmental impacts, which arise from a change in waste industry conditions and in this case particularly from a change in sorting and cleaning procedures, is thin on the ground. If, for example, an increase is achieved in the material stream which can be sent to a particular recycling process and is thus diverted from incineration, the consequences, or rather the environmental impacts of this are hardly described. From the examined feedstock recycling and energy recovery processes, one can deduce the improvement potential compared to bare incineration without energy decoupling.

4. Observations on the Choice and Determination of Criteria

68. Parameters from the German Federal Environment Agency's list of criteria for environmental assessment that would provide evidence of toxic impacts – *i.e.* the potential for direct damage to health and the potential for direct damage to ecosystems – are not taken into account. No characterisation of toxic categories was included, as there was no material-specific evidence for the waste streams examined or specific references to the transferability of available data. It is however certain that, at least in the case of some types of waste, there can be significant toxic impacts[5]. This applies particularly to waste types such as the shredder fluff analysed and assessed here and the mixed plastic waste from shredding operations.

69. For the comparison of the environmental impacts of the different processes of feedstock recycling and energy recovery in particular, compared with the reference system of incineration, this restriction of the criteria parameters is problematic and sensitive. For some heavy metals the transfer rate – the amount that is transferred from waste to air during recovery – is comparatively high. In Germany, specifically waste incineration plants are properly equipped to deal with emission problems of this kind. Specific advantages of the reference system, significant for a comprehensive assessment, are not considered, owing to the absence of an assessment of toxic impacts.

70. In conclusion, therefore, whilst acknowledging the results of this study, it should be emphasised that the evaluation was made without taking into account toxic criteria.

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5 Significant toxic impact is a specific category from the eco-efficiency study.

5. Sensitivity Analysis

71. In the LCA, sensitivity analyses were carried out for the main parameters identified in the dominance analysis, to the extent that such parameters were subject to uncertainty. The sensitivity analyses were carried out using the example of mixed plastics residue from mixed household waste.

72. For the different waste management systems there were variations in the sorting procedures and thus in the resource yields, specific electricity requirements, particularly in the case of energy and feedstock systems, and changes in the equivalence processes. The following assumptions were made:

- Material recycling: recyclate production with a substitution factor of 0.9 instead of 1.
- Feedstock recycling: the substitution of methanol from heavy oil instead of a mixture.
- Feedstock recycling: the substitution of hard coal for heavy oil for recycling in blast furnaces.
- Energy recovery: in the case of efficient waste incineration plants the production of steam only, instead of steam and electricity combined.

73. The discussion is based on the results of the global warming potential and the information on the primary energy demand. The two sets of information are based on similar data and lead to similar environmental impacts. For this reason the sensitivity analysis has limited validity.

74. The results show that, above all, substitution processes can have a significant influence on the outcome. This was especially noticeable in the case of feedstock recycling at the gasification plant "Sekundärverwertungszentrum" SVZ to produce methanol. In this instance a change in the industrial mix to produce methanol will result in significant savings by the substitution of heavy oil.

6. Significance of the Results

75. The German Federal Environment Agency's evaluation system is intended to put the environmental impact attributable to the investigated system in the context of the overall environmental situation or other environmental concerns. The purpose of the significance analysis, as it is termed, is mainly to put those to whom it is addressed, such as the environment policy decision-makers, in a position to assess the policy benefits of a scenario.

76. By presenting the results in population equivalent values, as documented in the results of the impact assessment, it is possible to gain an impression of the results in order of magnitude.

77. The difference between the results of two recovery systems in order of magnitude is illustrated in the example of the recovery of plastics from mixed household waste. To this end, the results of the impact assessment were normalised to population equivalent values for each management process, *e.g.* in MJ units over MJ per head of the population for an incineration plant with energy extraction. As a consequence, the normalised results can be interpreted as a population-equivalent figure, in relation to which the impact in Germany in the category examined increases or decreases through recovery.

78. For plastics residues occurring in mixed household waste the greatest reductions are achieved for the system with material recycling at S = 1 in some categories; in other categories the results are comparable with feedstock recycling and energy recovery systems. Feedstock recycling and energy recovery processes can lead to additional impact in the categories of acidification and eutrophication potential compared with the incineration plant reference. If higher energy extraction takes place in the incineration plant reference system, however, smaller reductions or greater additional impact are generally to be expected for all other processes by comparison. If the substitution factor S = 1 cannot be achieved with material recycling, the

results are no longer generally valid, especially when additional impacts from the use phase are taken into account.

7. Conclusions and Recommendations Resulting from the Environmental Analyses

79. The aim of the UFOPLAN project was a screening study in order to investigate initial indications and trends for optimising waste streams outside the Duales System Deutschland, responsible for the management of post-consumer packaging waste. The employers of the study were not only interested in knowing the best recovery solutions, but also in learning to what extent environmental impact could be reduced by exerting an influence on particular plastic waste streams. In subsequent steps, technical and economical feasibility were included in the consideration of forward-looking material flow management.

80. In the case of life-cycle analysis of material recycling, the problem with this study is that no specific assumptions could be made for the actual use of the recyclate, since – at least at that time – these recovery paths did not exist. Therefore, pragmatically, the LCA study only included an assessment as far as the recyclate stage and not as far as its use. The results for material recycling therefore characterise the ideal case in which the recyclate completely replaces virgin plastic (substitution factor S = 1). Whether this is accurate will have to be examined in later considerations of the specific recycling situation.

81. It was also assumed in the study that sorting residues that arise are sent for incineration. This assumption mainly affects material recycling operations, since relatively large quantities of sorting residues arise in these processes. Therefore, the available results for material recycling characterise the case in which sorting residues are completely disposed of by bare incineration. With the prerequisite that the sorting residues would undergo partial or total feedstock recycling or energy recovery, the LCA comparison would shift the result in favour of material recycling.

82. To summarise, it can be established that the following effects in particular are crucial to the environmental impact:

- The material characteristics and specifications of each waste stream.
- The specific recovery process in combination with the pre-treatment of the material stream.
- Other factors, such as level of energy extraction of a combustion plant such as MSWI, demand of process energy, losses, etc.
- The quantity of each waste type available for waste management processes.
- The proportion of this amount that is actually recovered by either material or energy.

83. It should be noted that only a few product-specific types of waste were selected by way of example for this study. This means that the specific waste types, that can viably be separated for collection, cannot be stipulated in general terms, and nor can the optimal processes of energy recovery or feedstock recycling. In practice, it must be assumed that all the recovery options are in fact feasible. The prerequisite for this is that the necessary treatment and recovery technology is actually available in practice and has the required capacity. Moreover, in the case of material recycling, the commercial viability of the recyclates is a particular requirement, *i.e.* it must exhibit a certain quality to have demand in the market.

84. All in all, it can be established that no one particular process can be implemented on its own to achieve the greatest possible reduction in environmental impact through optimised waste management. There are technical reasons alone why this cannot be done. Furthermore, a certain residue will always have to be incinerated, firstly because hundred percent collection is not realizable and secondly because certain types

of waste are not suitable for every recovery process on account of their specification. The results of the study show that from an environmental perspective:

- At general view, all recovery processes are better than landfill by aspects of resources savings and climate protection (see joint study of UBA / BMU / BDE) and, furthermore,
- In general no recovery process is superior to another. An overall waste management concept for plastic waste should consider all recovery possibilities (recovery mix). This general result is based on the environmental assessment, since the respective recovery option – mechanical, feed-stock or energy recovery – highly depends on the quality of waste stream;
- Efficient incineration is also a viable option, *i.e.* incineration where there is a high degree of energy recovery;
- Increasing recovery is desirable in principle and the largest possible amounts should always be recovered;
- Waste management paths that require major expenditure for pre-treatment of the waste or have tight restrictions on waste specifications should be avoided;
- The factors for an optimal recovery mix should be determined in each case and as a result the optimal solution may look different every time, depending on the source and type of waste;
- Increasing material recycling without regard to specific factors affecting individual industry sectors, enterprises or regions can prove counterproductive, which is why in many cases feedstock recycling or energy recovery are more suitable ways of recovering residues containing mixed wastes or wastes containing foreign material.

85. Methods: Depending on the specification of the recovery paths and the types of waste, the size of the material streams for the options investigated lies between 4,000 and 500,000 tonnes. As a result the environmental assessment shows that there is no process which is superior to other recovery alternatives in all circumstances, *i.e.* for all sources and all quantities and all categories. It is clear that reducing the impact on the environment does not only depend on the quality of the waste streams and the recovery paths, but also on the size of the stream. For viable recovery in practice, economic and social criteria must also be taken into account.

VII - ECONOMIC ASSESSMENT

86. As a further part of the investigation an economic assessment of the options which have been examined from an environmental perspective is attempted. The calculations are worked out using the cost of collection, transport, sorting/cleaning, recovery and lastly the revenue from sales of the recovery products such as granulates or energy. In general, the costs are based on market prices, or on estimates, if the prices were not available. Most of the systems investigated did not exist in practice at the time the study was undertaken.

87. As a result, none of the processes examined is more cost-effective than the incineration reference scenario. This means, that the efficiency of the process is decisive, for instance the energy output versus the mass input, which is well described in the European Reference Documents for Best Available Technologies of incineration and co-combustion processes (see reference European Commission: BREF Waste Incineration and BREF Large Combustion Plants). Only the recovery paths for waste cables, pipes and electrical/electronic casings, which have started to operate in the meantime, emerge as economically viable procedures. In the case of waste from private households, all recovery alternatives are more expensive than those practised previously. The authors judge the most expensive of all to be the material recycling of mixed household plastics and therefore do not consider this a viable option. Feedstock recycling is also shown to be fundamentally more expensive than incineration.

88. In the commercial sector, on the other hand, the separate collection of particular waste types allows for comparatively successful (or at least cost-covering) material recycling. This applies to the product groups of pipes, electrical/electronic casings and cable waste that were studied. Recycling other types is also conceivable, provided they are clean and unmixed. In the final analysis the economic success depends on commercial viability, *i.e.* taking into account factors such as product quality and the capacity of the market to absorb such products. This applies not only to the products of material recycling (recyclates), but equally to those of feedstock recycling (syngas or methanol) and energy recovery (heat, electricity, steam).

VIII - THE KEY FINDINGS

89. For non-packaging post-consumer plastic waste, material recycling within specific parameters tends to be the most environmentally sound management option. As the results of the LCA demonstrate, material recycling has advantages in all the impact categories scrutinised, not only over unsorted consignment to final disposal, but also, even if less markedly, over the alternative recovery options investigated.

- From an environmental perspective it is therefore sensible to extract the largest possible amount of plastics from mixed household waste and send it for material recycling.
- It also makes the most environmental sense to recycle materially the types of plastics from commercial wastes with a make-up similar to household waste which has been disposed of up to now, if they reach a specific quality level. The fact that the quantity of plastics to be recycled from commercial wastes of this sort is considerably smaller than that from un-segregated household waste might make mechanical recycling of it more difficult.
- Among the recovery options feedstock recycling and energy recovery, also the blast furnace technology is a preferable option from an environmental perspective. Other recovery routes are furthermore available with cement kilns or the production of methanol, where the latter is at present not being carried out.
- For plastics in bulky waste and commercial waste, which is managed by private-sector waste management entities, material recycling is reasonable from an environmental point of view for those types of waste that are readily identifiable and relatively easily and cleanly separated from the waste stream.
- Wastes suitable for material recycling on the basis of the LCA results are pipes and PUR foam from furniture, provided that they can each be collected in separate streams in the requisite quality. Other types such as car seats and plastic housings from the electrical/electronics sector are not attestable to be environmentally beneficial on the basis of the available results.
- Segregation at source of plastic waste streams for the purpose of feedstock recycling or energy recovery is not appropriate from an environmental point of view. The resulting environmental effects do not indicate any clear advantage of such a pre-treatment over thermal disposal in an inefficient incinerator.
- Plastic types from shredding operations are not suitable for material recycling. A comparison of the alternatives of feedstock recycling and energy recovery does not produce a clear result with regard to their environmental effects in the individual impact categories. Overall, the recovery of shredder residues for methanol production is assessed as better for the environment than recycling in a blast furnace, recovery in a cement kiln or in an energy-efficient waste combustion plant.

90. The authors of the critical review[6] point out the complexity of the study, which presents a combination of ecological, economical and other sub-studies, and emphasise that the results are not directly appropriate

[6] Dr. Rainer Grießhammer, Dr. Rolf Bretz and Carl-Otto Gensch, Öko-Institut, Freiburg.

for making specific decisions. Therefore, not a general conclusion can be made for all types of plastics-rich waste streams, but it shows that the one recovery route should be chosen taking comprehensive considerations into account depending on the waste quality, the collection infrastructure, treatment possibilities, recovery technology, markets of resulting products as well as costs and consumer behaviour. Nevertheless, the study offers scoping assessments, highlight tendencies and have a case-study character. The conformance of standard – the crux of the critical review – was essentially confirmed and the conclusions, which were kept cautious and general, declared to be reliable. Amongst other things, the critical review establishes that the selection of reference systems omitted combinations of recovery options (*e.g.* material recycling and energy recovery), and that human or environmental toxicology impact categories were not taken into account.

IX - CONCLUSIONS

91. The raw material for the production of most plastics today is mineral oil. It is cost-efficient and, in effect, using just a small amount of the overall oil production, but helping us to reduce the use of a far larger amount of primary energy resources in energy consuming applications and appliances. Plastics are used to make a whole range of products for crafts, households, leisure, sports, medicine etc. without reasonable substitutes. But when plastic products can no longer serve their purpose, they need to be recovered to save the value that has been invested in order to produce them.

92. Inside the plastics material, when the old products reach their end-of-life stage, can be utilised either by material recovery (= recycling) or by energy recovery, which immediately conserves primary resources. So where it is not technically or economically feasible to recycle the plastic material in any other way, energy recovery is the best option. It makes no sense to advocate reprocessing the old material just for the sake of it, there needs to be sufficiently large markets for products recovered from used plastics to be viable – be it in the field of recyclates, chemical raw materials or energy for other recovery options. There is no point in manufacturing new products that nobody wants to have.

93. As a matter of principle, it is important that all three recovery paths be used in plastic waste recovery. In order to receive optimum waste management efficiency, the complexity of the post-consumer waste streams, which do usually not solely consist of plastic streams, but of other materials too, as well as the respective local waste management structure, is crucial to be taken into account. A good waste management structure leads to high recycling rates, a second best management structure leads to high energy recovery rates and an un-recommended structure leads to high landfill rates.

X - INFORMATION SOURCES

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