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Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics

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Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics

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ABS	Acrylonitrile-butadiene-styrene
BAD	Bisphenol-A-diglycide ether acrylate
BBP	Bio-based polyester
CEN	European Committee for Standardization (French: Comité Européen de Normalisation)
DIN	German Institute for Standardization (German: Deutsches Institut für Normung)
RDF	Refuse-derived fuel
EVA	Ethylene vinyl acetate
OW	One-way
GPPS	General purpose polystyrene
GMO	Genetically modified organism
ILUC	Indirect land use change
CED	Cumulated energy demand
LUC	Land use change
MAPP	Maleic anhydride polypropylene
MKS	Mixed plastics
MOPP	Metallized oriented polypropylene
MW	Multi-way
RRM	Renewable raw materials
nPLA	nucleated PLA; up to 5% PDLA and the rest PLLA
OPP	Oriented polypropylene
OPS	Oriented polystyrene
OVAM	Public Waste Disposal Agency for the Flemish Region of Belgium (Flemish: Openbare Afvalstoffenmaatschappij voor het Vlaams Gewest)
PA6	Polyamide 6
PBAT	Polybutylene adipate terephthalate
PC	Polycarbonate
PCR	Post-consumer recycled
PCL	Polycaprolactone
PDLA	Poly-D lactic acid
PE	Polyethylene
PE-HD	High density polyethylene
PE-LD	Low density polyethylene

PE-LLD	Low density linear polyethylene
PET	Polyethylene terephthalate
PHA	Polyhydroxyalkanoate
PHB	Polyhydroxybutyrate
PLA	Polylactic acid
PLA-NG	PLA-next generation
PLLA	Poly-L lactic acid
PMMA	Polymethyl methacrylate
PVAL	Polyvinyl alcohol
PO	Polyolefines
PP	Polypropylene
PP-GF	Glass-filled polypropylene
PS-E	Expanded polystyrene
PS-HI	High-impact polystyrene
PUR	Polyurethane
PVC	Polyvinyl chloride
PVdC	Polyvinylidene chloride
PVOH	Polyvinyl alcohol
RED	Renewable Energy Directive of the EU
TGD	Tripropylene glycol diacrylate
GHG	Greenhouse gases
TPS	Thermoplastic starch
TPA	Terephthalic acid
VITO	Flemish Institute for Technological Research in Belgium

Report Cover Sheet

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16. Abstract

The 5th revision of the German Packaging Ordinance introduced special provisions for biodegradable plastic packagings, which are bound to expire on December 31, 2012. It is the intention of this research project to review the current regulation and to provide support to decision makers with respect to the future treatment of biodegradable packagings.

A market survey was carried out which revealed a maximum share of 0.5% of bioplastic packagings of the overall German plastic packaging market for the 2009 reference year. This showed that the market incentive for bioplastics achieved through the special regulation was marginal. It is expected that the share of bioplastic packaging will increase to roughly 1%-2% in the period between 2011 and 2015. There is also a trend towards plastic packagings which are bio-based but non-biodegradable. Consequently, both biodegradable as well as bio-based but non-biodegradable plastic packagings were comprised in the research project.

In 2009, used bioplastic packagings were mostly recovered energetically. Composting did not gain a relevant share as a disposal route for used bioplastic packagings, which was in contrast to expectations initially raised.

Life cycle assessment (LCA) studies often show smaller impacts for bioplastic packagings as compared to their fossil-based counterparts when it comes to greenhouse gas emissions and fossil resource consumption, but they do not typically achieve overall environmental superiority over the fossil-based counterparts. Compostable bioplastic packagings contain shares of fossil-based copolymers and usually are heavier in weight. LCA results of this group of bioplastic packaging therefore may even show an unfavourable overall environmental performance as compared to the fossil-based counterparts. Environmental optimization potentials of bioplastic packaging are found in the area of biomass production (selection of adequate crops, improvement of farming operations, use of residual biomass or lignocellulose) as well as in the area of biomass conversion (improved energy efficiency and product yield).

Neither ecological aspects nor the current waste management situation of bioplastic packagings call for immediate action aimed at continuing the special treatment of biodegradable packagings. Further political support of bioplastic packaging in the context of the Packaging Ordinance should be coordinated with already existing support instruments regarding the utilization of renewable raw materials.

17. Key words: Packagings, bioplastics, waste policy, Packaging Ordinance, life cycle assessment

1 Introduction

1.1 Background and objectives

The market relevance and presence of packagings made of biodegradable plastics has increased over the past few years. They are primarily used as alternatives for conventional plastics such as polyethylene (PE), polypropylene (PP), polystyrene (PS), and polystyrene terephthalate (PET).

The biodegradable plastics used for manufacturing packagings are predominantly made from renewable raw materials including, for example, starch-based plastics, polylactide (PLA), polyhydroxyalkanoate (PHA), and cellulose-based plastics. There are also biodegradable plastics made from fossil, non-renewable resources (e.g. copolyesters).

The 5th revision of the Ordinance on the Avoiding and Recovery of Packaging Wastes (Packaging Ordinance, VerpackV[1]) constituted a special regulation for packagings made of biodegradable plastics that was meant to at least partially compensate for their less favourable cost. The special provisions for biodegradable materials are contained in section 16 of the Packaging Ordinance; in simple words, the following parameters are set:

Exemption from ensuring the large-scale return of sales packagings until December 31, 2012[2]

> However, this exemption is tied to the requirement that "*the share of packaging recovered is as high as possible*"[3].

Biodegradable one-way beverage packagings are exempt from deposits and the obligation to take them back by December 31, 2012 under the condition that these "*made from renewable resources to at least 75 percent*"[4].

> If an exemption from having to collect a deposit is granted, packaging return across the entire sales area must still be ensured[5]

[1] Packaging Ordinance of August 21, 1998 (Federal Law Gazette I p. 2379), last amended by the 5th Amendment to the Packaging Ordinance of April 2, 2008 (Federal Law Gazette I p. 531)

[2] Section 16 (2): "Until 31 December 2012, sections 6 and 7 shall not apply to plastic packaging made from biodegradable materials, all components of which are deemed compostable according to producer-independent certification conducted using recognised standards."

[3] Section 16 (2): "Producers and distributors shall ensure that the share of packaging recovered is as high as possible."

[4] Section 16 (2): "Until 31 December 2012, section 9 shall not apply to plastic one-way drinks packaging complying with the provisions of the first sentence above and made from renewable resources to at least 75 percent, insofar as manufacturers and distributors take part in one or several compliance schemes under section 6 subsection (3) with respect to this packaging. Compliance with the condition stated in the third sentence above, according to which the one-way drinks package must be made of at least 75 percent renewable resources, must be verified by an independent expert within the meaning of No. 2 subsection (4) of Annex I. In other respects section 9 shall remain unaffected."

[5] In the case described in the third sentence and where one-way drinks packaging made from biodegradable plastics pursuant to the first sentence above is not subject to the mandatory deposit pursuant to section 9 subsection (2), in derogation from the first sentence

This means that temporary facilities are in place for biodegradable plastics with respect to implementing product responsibility and recycling requirements as well as a temporary exemption from the obligation to collect a deposit for one-way beverage packagings.

These temporary regulations are meant to support the development of the market for biodegradable plastics in Germany. Since the licensing fee for plastics can sometimes be as high as the material price, this can be an important economic incentive for using biodegradable plastic packagings.

The Transitional Provisions of section 16 of the Packaging Ordinance are limited in time until December 31, 2012. The legislator will then have to decide how the topic of biodegradable packagings is to be handled in the future. It is therefore an objective of this research project to review the existing regulation and to contribute to the further development of the Packaging Ordinance.

The project has the following detailed goals:

1. Analysis of the current market situation (2009) of biodegradable plastic packagings in Germany.

   This step should ideally provide a quantity structure of biodegradable plastic packagings in Germany by types of plastics used and by packaging applications.

2. Analysis of the current disposal situation (2009) of biodegradable plastic packagings in Germany.

   This step should ideally provide information on which percentages of biodegradable plastics are placed on which recycling and disposal routes.

3. Market and disposal situation forecast in Germany (2010–2015)

   This step should refer to the analysis of the current situation and estimate the development of the consumption and recycling of biodegradable plastics for packaging purposes in the period from 2010 to 2015.

4. Survey of opinions on the Packaging Ordinance

   This step is aimed at obtaining a survey of current opinions on the existing regulation for packagings made of biodegradable plastics among the affected companies and associations. The focus of the survey will be on determining and reflecting prior experience the individuals affected have gained and their expectations with respect to the future treatment of biodegradable packagings in the Packaging Ordinance.

5. Ecological evaluation

   The ecological evaluation of biodegradable packaging materials is at the focus of the research project. The goal is to make reliable statements about the ecological significance of biodegradable plastics as compared to conventional plastics. Existing studies will be analysed for this purpose. Comparative life cycle assessments are of particular importance here, because often consideration of the entire life cycle only makes strengths and weaknesses of biodegradable packagings apparent.

6. Aspects of competition for areas

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above, manufacturers and distributors shall take part in a compliance scheme pursuant to section 6 subsection (3) with respect to this packaging insofar as the packaging arises at the private final consumer.

This step is to outline the current state of affairs of this competitive relationship and potential sources of conflict. It is to point out open questions and the need for further studies.

7. Conclusions and recommendations

   Finally, the findings of goals 1 to 6 will be pooled. The analysis should include informed conclusions and make recommendations for the future treatment of packagings made of biodegradable plastics in the Packaging Ordinance.

For the conclusions, the Packaging Ordinance should also be viewed in the wider context as a subordinate set of rules of the Closed Substance Cycle and Waste Management Act (KrW-/AbfG). According to section 1(1), it is the purpose of the Packaging Ordinance "to avoid or reduce the environmental impacts of waste arising from packaging". Furthermore, where packaging waste cannot be avoided, "reuse of packaging, recycling and other forms of recovery shall otherwise take priority over the disposal of packaging waste".

In addition, when evaluating the overall waste hierarchy as defined in section 6(1) of the amended closed substance cycle and waste management legislation[6] is to be taken into account. Section 6(2) therein highlights the importance of life cycle assessments as a basis for evaluating disposal options.

1.2 Procedure

It became clear at the outset of the research project that useful statistics on the production and consumption of plastic packagings do not yet exist [UBA 2009]. It was also apparent that biodegradable plastic packagings are not listed separately in the annual volume flow record kept by system operators about the packagings they collected, sorted, and recycled in accordance with the Packaging Ordinance, section 6(3).

Therefore, a poll was held among the respective market players. The poll addresses goals 1, 2, 3, and 4. It was conducted by sending out questionnaires and by contacting respondents directly by phone, through appointments, or at the Interpack 2011 fair.

The questionnaire (see Appendix III) was developed in coordination with the Federal Environmental Agency. It was sent to the member companies of Industrievereinigung Kunststoffverpackungen e.V. (Industrial Association for Plastic Packagings), Bad Homburg, and European Bioplastics (EuBP), Berlin. Both industrial associations supported the mailing by a cover letter and provided feedback on the design of the questionnaire. A questionnaire adjusted to the target group was also sent out to selected disposal companies and associations.

The data collected was supplemented by an Internet and literature search. Position papers and press releases were also taken into account.

A literature analysis of LCA studies had been planned from the start for the ecological evaluation. This is why we conducted an extensive Internet search for literature. For details, see Chapter 4.1. The references found were analysed in two degrees of depth:

1. Basic analysis
2. In-depth analysis

[6] Notification by the EU is currently pending (September 2012).

The list of references searched and the grid of criteria used are included as an Excel file in Appendix V.

The research project is also aimed at findings that go beyond the classic ecological assessment that is mainly focused on impact categories. A frequently discussed topic is the question if the cultivation of renewable raw materials for producing energy on arable land is competing with growing food plants. It has been stated on several occasions that the increase in use of arable land for renewable raw materials in recent years has contributed to the cause for considerable variation in food prices and the related scarcity of basic foodstuffs.

This project studied two aspects of the issue in greater detail:

Land use by bioplastics as a function of available land

Bioplastics as a potential factor influencing price volatility

It is imperative that we look beyond Germany in this context, not least because of the growing international trade in renewable raw materials and the supply chains for the bioplastic packaging product line, which are already international today.

1.3 Terminology

As yet, there are no unique, generally accepted definitions for the terms used in conjunction with bioplastics and biodegradable plastic packagings.

At least, the European standardization body has made first recommendations on harmonizing the terminology in its draft technical report titled “CEN/TR 15932”[7].

According to this report, bioplastics (biopolymers) can be classified based on the following aspects:

1. Polymers that are based on renewable raw materials:
    a. Natural biomass-based polymers
       Polymers produced by living organisms (animals, plants, algae, microorganisms): Cellulose, starch, proteins, or bacterial polyhydroxyalkanoates
    b. Synthetic biomass-based polymers
       Polymers whose monomers are based on renewable raw materials but whose polymerization requires a chemical transformation, e.g. PLA, ethylene, polyamide
2. Polymers that comprise “biofunctionality”:
    a. Polymers for biomedical application
    b. Biodegradable polymers
       Polymers that are used in biodegradable products and can therefore be recycled organically

A polymer is a chemical compound consisting of chain or branch molecules (macromolecules), which themselves consist of same or similar units, so-called monomers. Bioplastics are typically considered polymers.

[7] “CEN/TR 15932: Plastics — Recommendation for terminology and characterisation of biopolymers and bioplastics”

However, the classification of biopolymers according to CEN/TR 15932 is not helpful in this study. We will therefore provide a brief explanation of the terms used in this report.

The terms biopolymer and bioplastic are used synonymously. The term bioplastics covers different groups of materials that are characterized by one of the following properties:

- Materials that are at least partially made from biomass (bio-based), regardless of biodegradability
- Materials that are biodegradable as defined by accepted standards (e.g. EN 13432)
- Materials that have both properties at the same time

In analogy, the term bioplastic packagings includes the following groups:

- Biodegradable plastic packagings (fossil or bio-based)
- Non-biodegradable bioplastic packagings (fully or partially bio-based)
- Biodegradable and at the same time bio-based plastic packagings

The terms listed below are also relevant in the context of this study.

Conventional plastics: non-biodegradable plastics based on fossil raw materials

Copolymer: Plastic built from different monomers that can be both fossil or bio-based

Biodegradability: Suitability for biological degradation, i.e. decomposition by living organisms or their enzymes down to mineralization such that the organic compounds are decomposed into substances like carbon dioxide, oxygen, and ammonia. In contrast to compostability, biodegradability is an inherent property that is independent of time and space while compostability is specifically related to the conditions in a composting plant.

The biodegradability of a material/product is tested by a biodegradability standard worked out by the International Standards Organization (ISO), ISO 14855. In contrast to compostability standards, this standard does not include a test for ecotoxic effects and disintegration.

The term “biodegradable” does not include the oxo-degradable plastics that are often also called biodegradable (see the definition for oxo-degradable materials below).

Compostability: Capability of biological degradation in a defined time under controlled conditions in a composting plant. Compostability is certified by DIN Certco (an EU-accredited certification institute) based on various standards [Schnarr 2010]. In addition to the Comité Européen de Normalisation (CEN) with the EN 13432 standard for bioplastic packagings and EN 14995 for plastic waste, other organizations have established standards regarding compostability testing methods:

- American Society for Testing and Materials (ASTM) ASTM 6400-99
- Deutsches Institut für Normung (DIN) DIN V49000

The European standard requires 90% degradation within 90 days and is therefore stricter than ASTM, CEN, and DIN, which stipulate 60% degradation within 180 days.

All standards have the following 3 criteria in common:

1. Biodegradation: Biodegradability according to EN 14046 (or ISO 14855), i.e. measurement of the metabolization of the compostable material in CO_2
2. Disintegration: Fragmentation, i.e. visible degradation of the product in the final compost according to EN 14045
3. Ecotoxicity: No toxic effects on microorganisms and plants and no adverse influence on the composting process

The term “biodegradable” is therefore not equivalent to “compostable”. However, due to the way these terms are handled in practice, this report typically means “compostable plastics” when referring to “biodegradable plastics.”

Bio-basedness: based on renewable raw materials.

This property can be proven using the radiocarbon method (also called 14C dating) in accordance with standards ASTM D-6866 or CEN/TS 16137. This method is based on the fact that the amount of bound radioactive 14C atoms diminishes in dead organisms in accordance with the law of decay. No 14C atoms can be detected for fossil carbon due to its old age.

There are two ways to indicate the bio-based portion of a product/material, either in relation to

- the overall carbon content of the plastic=bio-based carbon content:
- the percentage by weight of biomass in the plastic=biomass content

These values can differ because the latter also includes other chemical elements such as oxygen, hydrogen, or nitrogen. For example: Coca-Cola correctly states the biomass content in the PET PlantBottle as 30 percent, its bio-based carbon content however is 20 percent [European Bioplastics 2011b].

A dual minimum requirement has been defined for the test according to the DIN Certco (Gesellschaft für Konformitätsbewertung mbH) certification programme. The specified minimum content of organic material must be 50% and the percentage of bio-based carbon must exceed 20%. There are 3 classes with different percentages of bio-based carbon:

BIOBASIERT > 85 % DIN Geprüft

BIOBASED 50 - 85 % DIN Geprüft

BIOBASED 20 - 50 % DIN Geprüft

The test according to the certification programme by Vincotte (a Belgian certification service provider) also requires a content of at least 30% bio-based carbon and 20% biomass for awarding the certification symbol. The biomass content is measured using ASTM D6866, and the bio-based carbon percentage is determined using the TS-OK20 standard by Vincotte[8]. Four classes from 1 to 4 stars are distinguished based on the percentage of biomass contained in a product.

between 20% and 40% bio-based	between 40% and 60% bio-based	between 60% and 80% bio-based	more than 80% bio-based

Oxo-degradable plastics: Oxo-degradable plastics are not actually considered biodegradable plastics because their degradation process has two steps and requires additives. The first step, frequently called fragmentation because it produces microscopically small fragments, is triggered by UV radiation and oxygen. The second degradation step is the typical biodegradation of these chains into their original elements by microorganisms. Unlike the process for compostable products, this process is not subject to a predetermined time limit and may take years. In contrast to compostable plastics, the ecotoxic effects of this process are not exactly known. Oxo-degradable plastics can be characterized as oxo-biodegradable based on ASTM 6954-04, but this report does not rate them among biodegradable plastics.

[8] www.vincotte.com/

2 Market analysis

This chapter presents data on the German market for bioplastic packagings. Section 2.1 gives an overview of the German plastic packaging market. Section 2.2 compiles figures regarding the market for biopolymers. Section 2.3 contains information on the current German market for bioplastic packagings and an evaluation of future market development.

The information provided in Section 2.1 allows pinpointing the position of bioplastic packagings within the overall German plastic packaging market. The information in Section 2.2 gives us an overview of the global polymer development and provides indications of the relevance of each material type.

2.1 Plastic packagings in Germany

Information on the use of plastics in Germany can be found in [IK2010] and [Consultic2010]. But the data provided there also includes the entire plastic area and was therefore edited by IFEU to obtain a view of the plastic packaging sector.

Figure 1 shows the packaging consumption in Germany in 2009. The figures are based on the overall processing of plastics in Germany [Consultic2010, p.6], the total consumption of plastic materials in the packaging sector of 2645 kt [Consultic2010, p.9], and the estimate of the percentages of the packaging sector in the use of each type of plastic [Consultic2010, p.7].

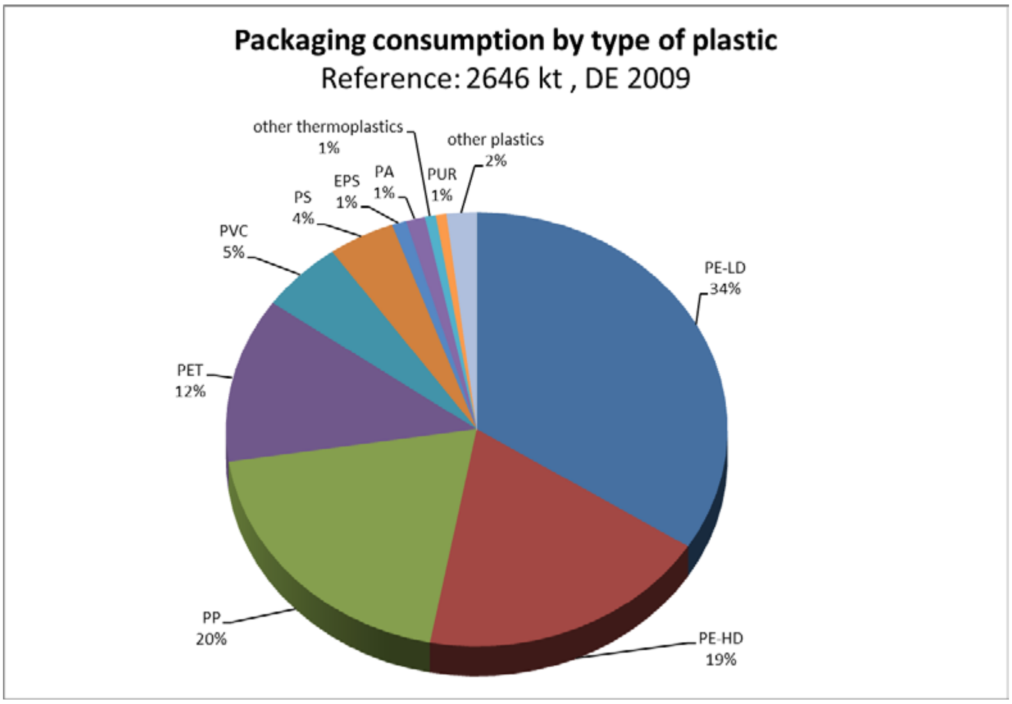

Figure 1: Packaging consumption by type of plastic in Germany (2009)

Source: Edited by IFEU based on [Consultic2010]

It turns out that 85% of the packagings used are made of polyolefins (PE and PP) and polyethylene terephthalate (PET). The percentage of polyvinyl chloride (PVC) and polystyrene (PS) jointly makes up 10%.

Figure 2 shows the fields of application where the plastics are used. The production data for plastic packagings [IK2010, p.41] was pooled with export share information [IK2010, p.42] and information on the consumption of plastic packagings [IK2010, p.43] to derive a quantity structure. The reference quantity of total consumption is the same as in Figure 1: 2646 kt.

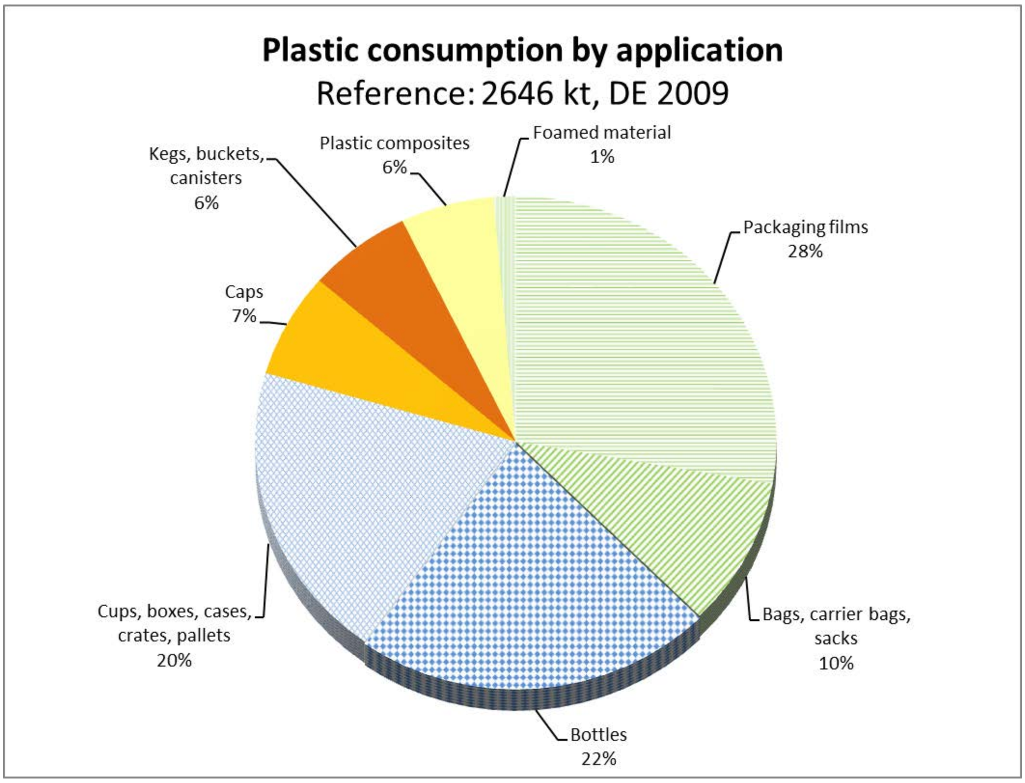

Figure 2: Plastic consumption by application in the packaging sector in Germany (2009)

Source: Edited by IFEU based on [IK 2010]

The application typology visible in Figure 2 is based on [IK2010]. It is apparent that film products are one of the main applications in the packaging field. The group of packaging films presumably includes both flexible films and semi-rigid films (for thermoforming applications). All products in the group of bags, carrier bags, sacks should be made of flexible film products and nets. Another important field of application includes bottles and other shape-retaining applications such as tins, cups, cases, etc.

The information in [IK2010] and [Consultic2010] does not indicate which types of plastic are used for which applications. IFEU assumes the following distribution:

- Polyethylene (PE) dominates among flexible film products but propylene (PP) is also used in this area
- Polypropylene (PP) and polystyrene (PS) should be predominant among semi-rigid films but are increasingly replaced by polyethylene terephthalate (PET)
- PET and PE-HD (high-density PE) are the most common materials used for bottles
- PP and PE-HD are the most common materials used for shape-retaining products like cups, tins, etc.

- PP and PE-HD are also predominant among caps.

The colours green and blue in Figure 2 mark the fields of application for bioplastics:

- Green stripes: Main field of application for bioplastics in 2009
- Blue checked: additional important applications of bioplastics as from 2010

(for more information, see Section 3.3)

2.2 Production capacity for bioplastics

Data on the global production of bioplastics is collected by Hannover University of Applied Sciences on behalf of the European Bioplastics Association (Berlin) from all known manufacturers of bioplastics [European Bioplastics 2011]. The information in Figure 3 relates to production capacities and does not necessarily reflect the quantities actually produced.

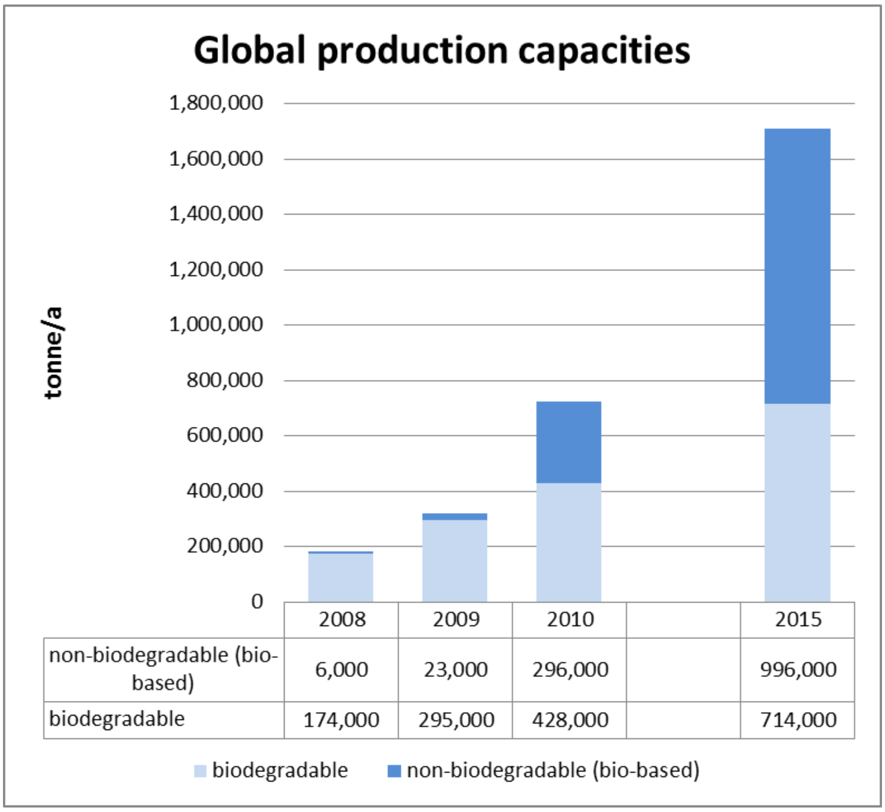

Figure 3: Global production capacities for bioplastics

Source: [European Bioplastics 2011]; diagram provided by IFEU

Figure 3 shows that bioplastics were mostly biodegradable until 2010. The projection for 2015 shows that the percentage of non-biodegradable bioplastics could become predominant in the future.

The global scope of the data in [European Bioplastics 2011] does not allow conclusions regarding production in Germany. This would not make much sense because the materials for the bioplastic packagings produced in Germany originate from a global raw materials market.

Information on the distribution of global production capacities across material types can be found in Figure 4 for reference years 2010 and 2015 and in Figure 5 for reference years 2009-2015 and 2020. The two figures differ only in the sources they are based on. While Figure 4 refers to data from [European Bioplastics 2011], Figure 5 is based on data from [Pro-Bip 2009] and own research.

The biodegradable materials are in the top portion, the non-biodegradable in the bottom portion of the diagram.

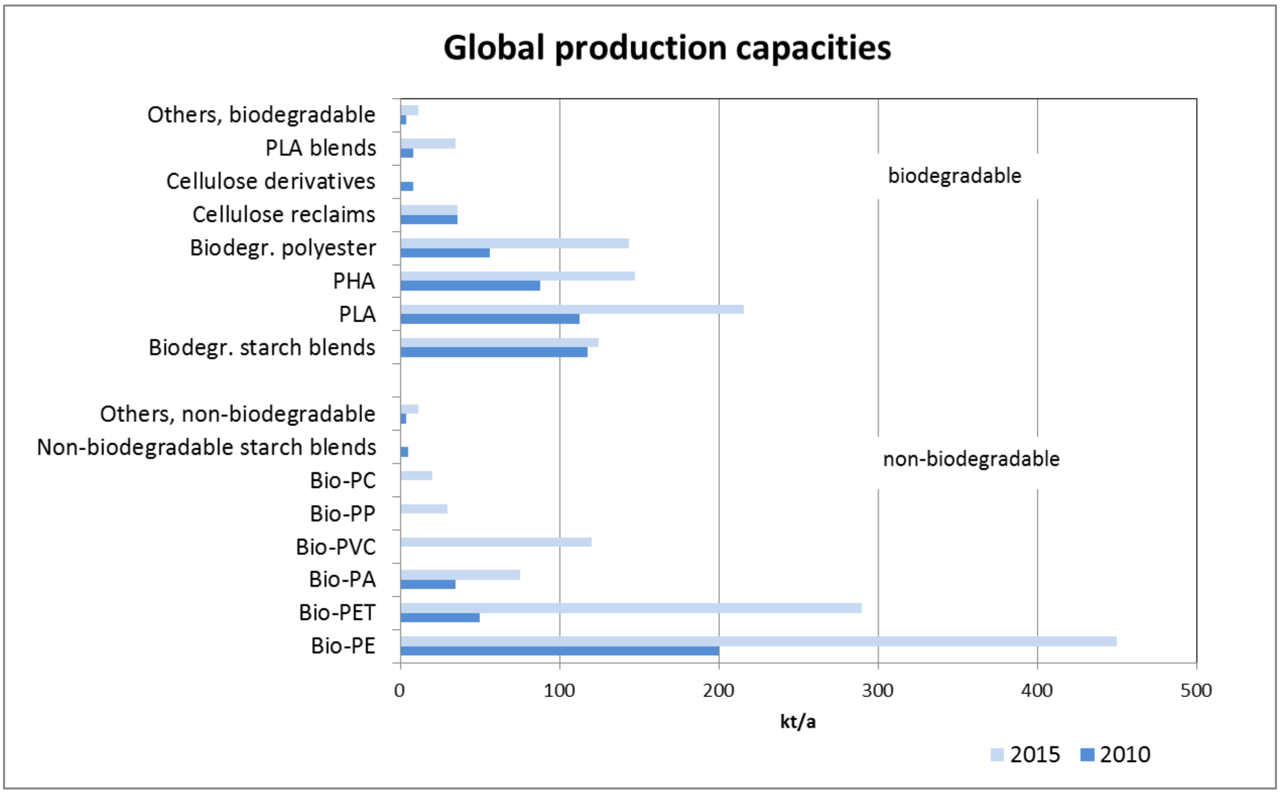

Figure 4: Global production capacities for bioplastics by type of plastic

Source: [European Bioplastics 2011]; graph provided by IFEU

The non-biodegradable bioplastics are predominantly of the same material as conventional plastics PE, PP, PET, PA, PC, and PVC. What is different is the raw material basis, which is partially or fully bio-based for these bioplastics. Bio-PE and bio-PET are expected to bind the largest capacities in the coming years. Both materials have been in the market since the end of 2009 (bio-PET) and beginning of 2011 (bio-PE) only. The main area of application of these materials should be the packaging sector in the years ahead (IFEU estimate: >80% of the bio-PE and bio-PET quantities produced).

Users assume that these bioplastics will show the same behaviour as conventional plastics in processing. This is also expected for recycling but has still to be proven in practice [Christiani2011].

The largest production capacities among biodegradable plastics can be found for PLA, starch blends, polyesters, and PHA. The three materials mentioned first are used the most in the packaging sector (IFEU estimate: >85% in 2009). The packaging sector may be less relevant in the future for these plastics [Pro-Bip 2009], but should still be the main application in the foreseeable future (IFEU estimate: 60%-70% in 2015).

Substantial growth has been forecast for these materials for the years to come. Starch blends are an exception according to [European Bioplastics 2011]. [Pro-Bip2009] however assumes that the global production capacities for starch plastics will continue to grow (Figure 5).

Both Figure 4 and Figure 5 show the global production capacities for bioplastics. But the data shown originated from different sources and will therefore allow a cross-comparison of estimates on the development of global production capacities. Figure 5 additionally lists bio-based monomers whenever available referred exactly to these. The type of plastic assumed to be produced of these is listed in brackets.

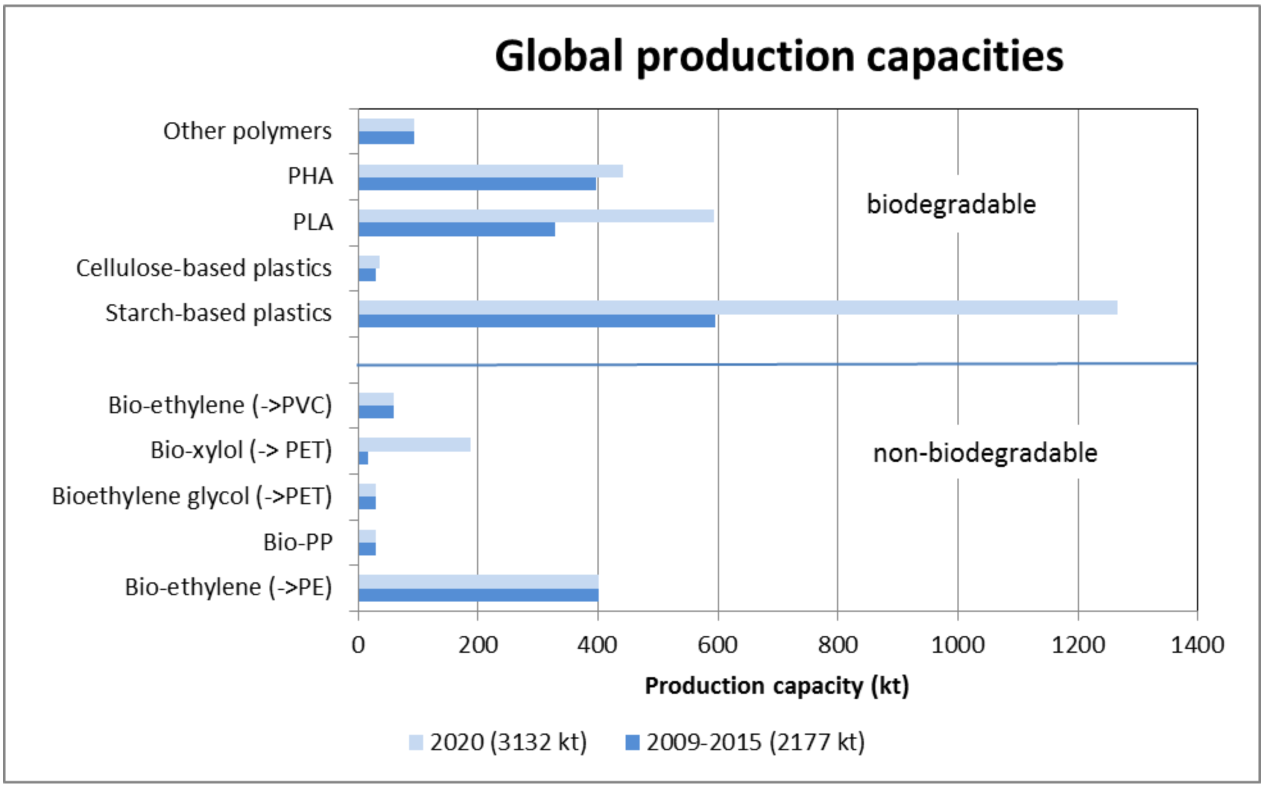

Figure 5: Global production capacities for bio-monomers and bioplastics made from them, e.g. bio-ethylene is the monomer for producing polyethylene (-> PE)

Source: [Pro-Bip2009] and own research; diagram and edits by IFEU

According to [European Bioplastics 2011], the “1 million metric ton mark” was reached in the global production capacity for bioplastics in the first half of 2011. The capacities are almost evenly distributed among the five regions of Europe, North America, South America, and Asia/Oceania (Figures 6 and 7).

The distribution in per cent shown in Figure 6 refers to the production capacities in 2010 that are listed for the same reference period in Figure 3.

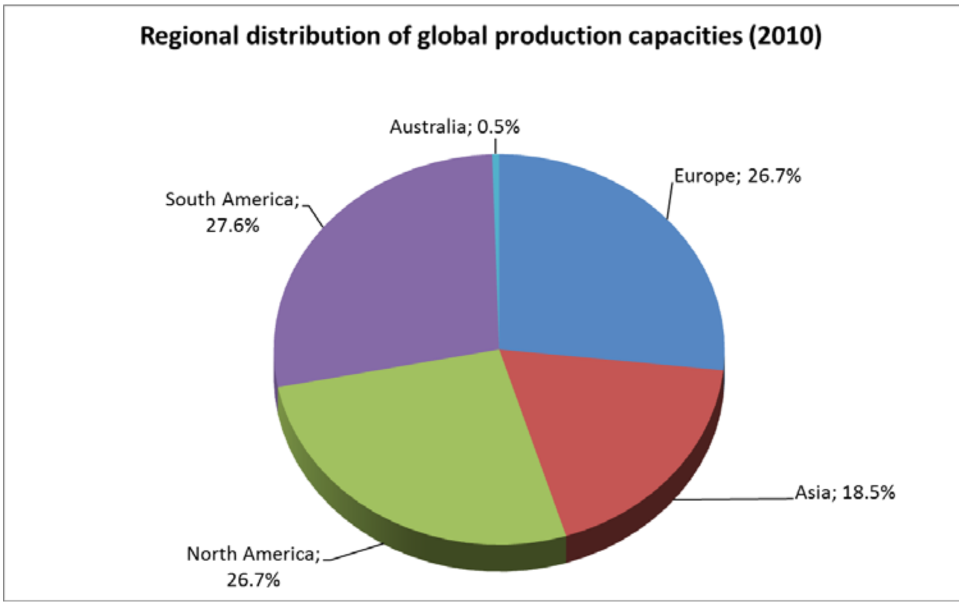

Figure 6: Regional distribution of global production capacities for bioplastics (2010)
Source: [European Bioplastics 2011]; diagram provided by IFEU

Figure 7 shows another representation of global production capacities. It lists bioplastics by manufacturer. The manufacturers based in Germany are marked by an additional "(DE)" entry. According to this diagram, BASF and BIOTEC are the two Germany-based manufacturers with such production capacities. There are other manufacturers, e.g. FKuR, but no data is available for their production capacities.

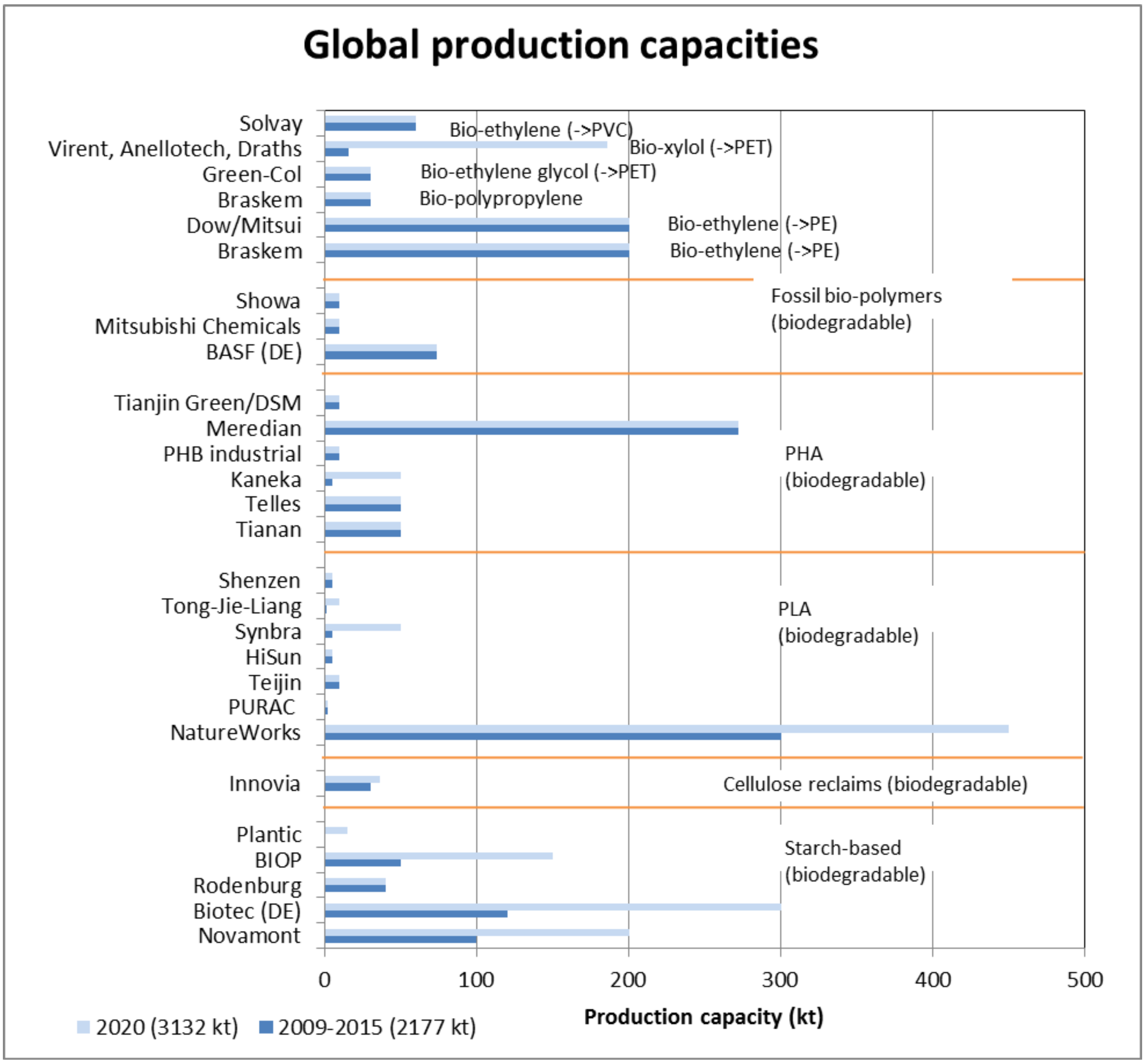

Figure 7: Production capacities for bioplastics by manufacturer

Source: Edited by IFEU based on [Endres 2009], [Pro-Bip2009], and various press releases ("→" indicates the bioplastics manufactured from the monomers listed)

In view of the limited production capacities in Germany, one can assume that it is mostly processing of the biopolymers into materials for manufacturing packagings (compounds) or packaging manufacturing itself that takes place in Germany. BIOP also develops engineering products in Germany but their business model is structured such that the BIOPAR bioplastic is produced based on a licence at the licensees' locations.

[Endres 2009] lists biopolymers by the number of their global processing companies (Figure 8). Processing companies for PLA-based and starch-based biopolymers are predominant, which basically confirms the previously visible significance of these two material groups in the bioplastics market as yet.

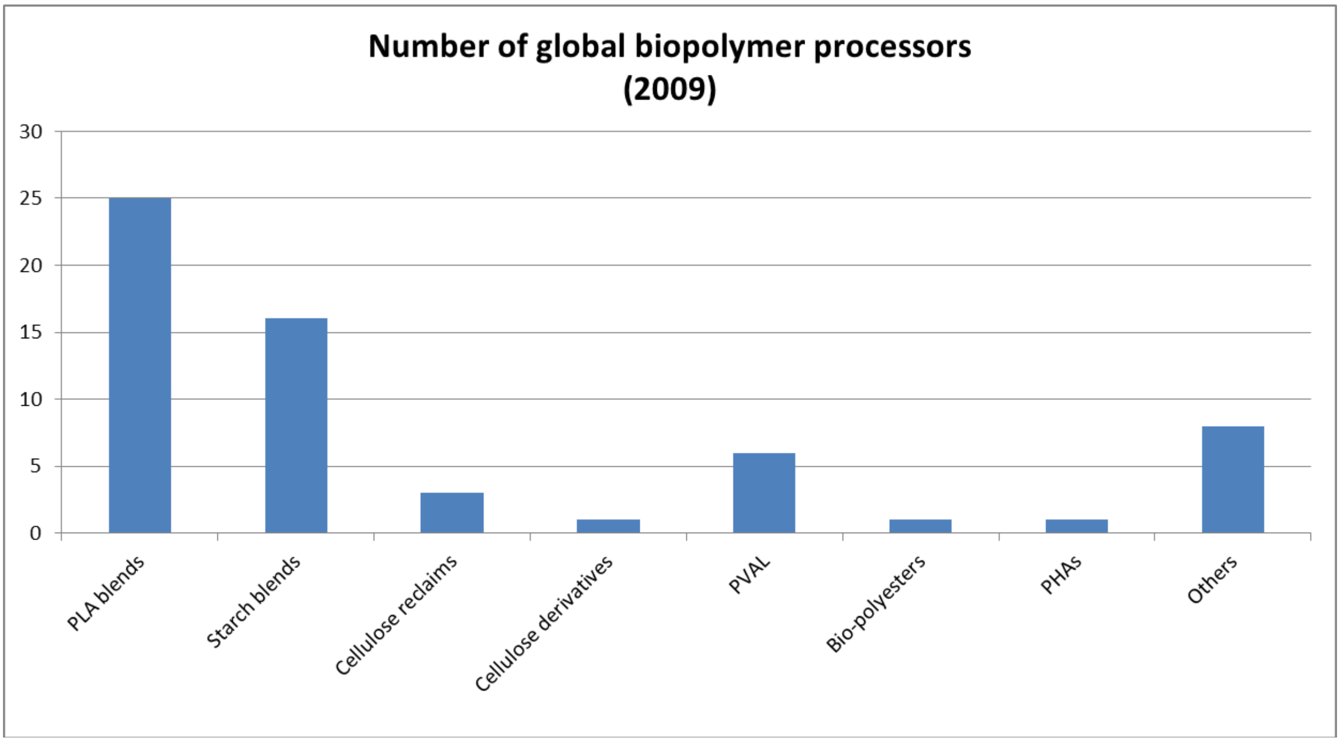

Figure 8: **Companies processing biopolymers by material type (2009)**
Source: [Endres 2009]; diagram provided by IFEU

Processing the bioplastics listed in Figure 8 typically requires adjustment of existing machines and tools. Processing companies typically develop the know-how themselves that can decide if they will be able to compete. In addition, each processing method requires that special adjuvants and additives (lubricants, UV stabilizers, impact modifiers) and others are worked into the plastic matrix to adjust both processability and the technical properties of the bioplastics to the profile of requirements to be met.

It is assumed that bioplastics such as bio-PE or bio-PET which consist of the same material as conventional PE or PET will not require any further machinery adaptation and that additives that are already tested can be used. The processing companies would then be identical with the existing companies processing conventional plastics.

There are no up-to-date publicly available figures on amounts of bioplastics consumed in Germany. European Bioplastics estimates that the consumption was 100,000 metric tons in Europe in 2007 while estimates by Fachagentur Nachwachsende Rohstoffe (FNR)[9] are in the range from 60,000 to 70,000 metric tons. These figures do not allow drawing any direct conclusions on the use of these materials in the packaging sector.

[9] Marktanalyse Nachwachsende Rohstoffe Teil II. Fachagentur Nachwachsende Rohstoffe e.V., Gülzow 2007

2.3 Packagings made of bioplastics in Germany

The market situation for bioplastic packagings in Germany as derived in this Section is partially based on data collected in a questionnaire campaign. Another source of information were background interviews (by telephone and at face-to-face appointments) with representatives of the industry, which contributed more quantitative data on individual products. This information could only be obtained with our assurance of strictly confidential treatment of the information received.

In most cases, we cannot name the individual manufacturers and the quantities of their products for reasons of confidentiality. This also applies to most of the individuals contacted, who also did not wish to be named. Consequently, we can present volume flows in aggregated form in this report only.

The information received is certainly not sufficient to derive a representative picture of the industry based on statistically sound information. All in all, the questionnaires sent back and the information received in the background interviews provide a rather clear picture. The result presented here has to be viewed as an expert opinion.

The data collection inevitably involves some uncertainty because the various customer relations and specific delivery relations between bioplastics manufacturers and processing companies are not known. We cannot rule out duplicate counts.

Biodegradable trash bags are a special case; the Packaging Ordinance does not count them as packagings. But they are part of the product portfolio of manufacturers of various film packagings. It should be assumed for the market analysis performed that the quantities provided for film packagings include a percentage of biodegradable trash bags that cannot be determined exactly.

Analysis of the current situation

The information on bioplastic packagings in the German market is provided in this Section in relation to the total volume of plastic packagings due to the confidentiality of the information collected from market participants. It was 2,645,000 metric tons in 2009.

According to our findings, the percentage of bioplastic packagings in the plastic packagings market was clearly below 0.5%, based on the volume information requested. To compensate for potential duplicate counts on the one hand and for the fact that not all relevant bioplastic packaging manufacturers have provided data on the other, the authors consider 0.5% as the upper limit to be a realistic estimate of the market share.

See Figure 9 for an estimate of the shares of individual material groups. According to this diagram, 80% of the bioplastic packagings used in 2009 were made of starch blends while about 20% were made of PLA. It was not always possible to distinguish exactly between products that were virtually produced from PLA alone and those produced from PLA blends. PLA blends may have a somewhat greater weighting in practice.

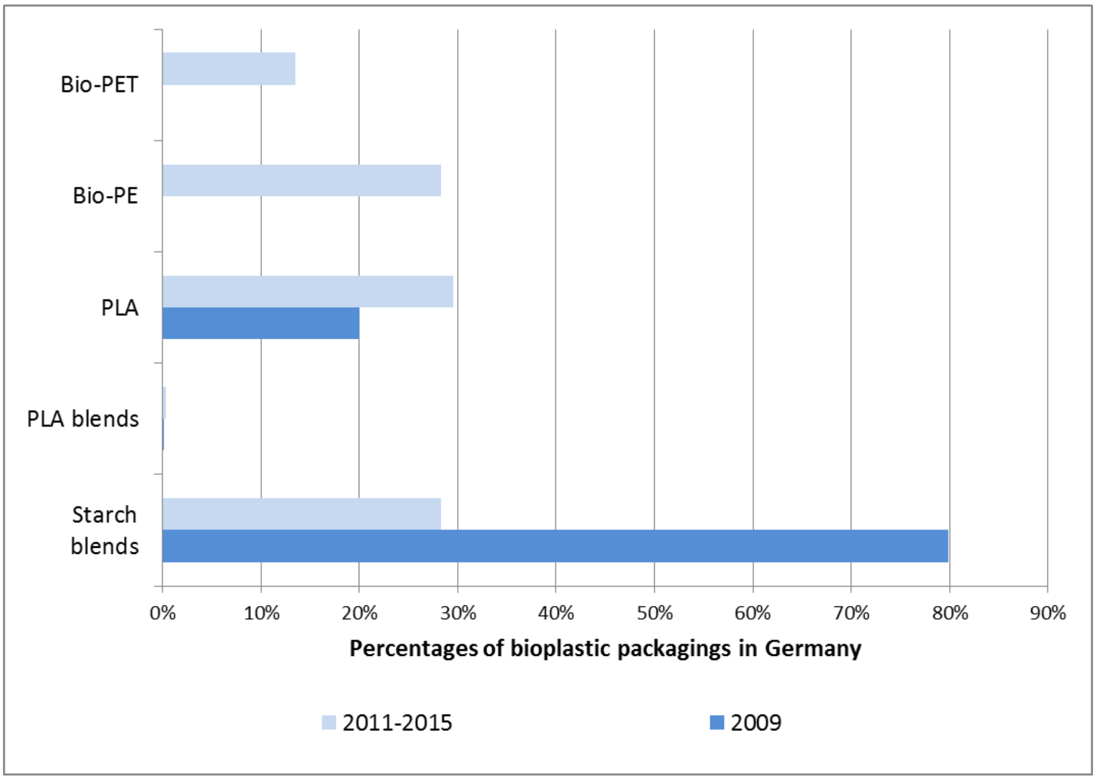

Figure 9: Percentages of bioplastic packagings by materials. Source: IFEU market survey
(The share of bioplastics in the packaging market in Germany in 2009 was <0.5% and is expected to be 1%-2% in 2011 to 2015)

See Figure 10 for an estimate of the relative shares of the packaging applications. According to this diagram, bioplastics were mainly used for flexible film packagings and as loose fill packagings in 2009. Cups and bowls are estimated to have had a very low share in the packaging market in 2009. As far as the authors know, bottles made from bioplastics were not used in the German market in 2009. Materials used for flexible films were starch blends, PLA blends, and also cellulose-based materials. The share of the latter was very low and could not be exactly determined based on data feedback received.

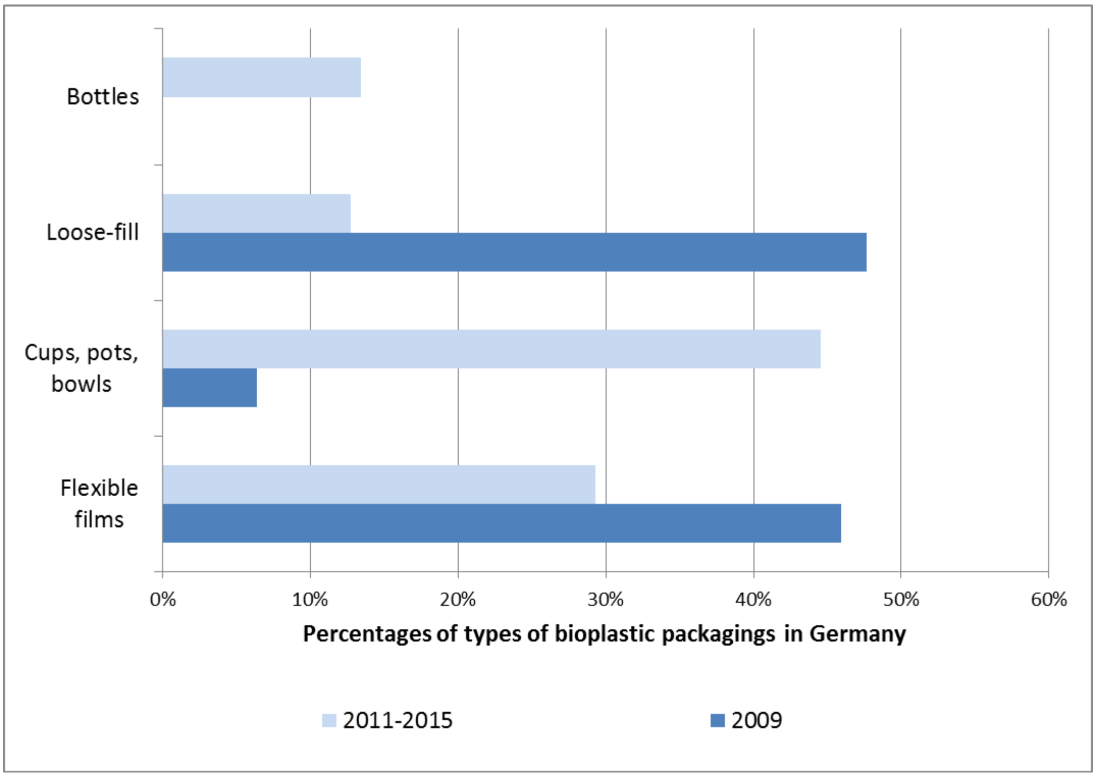

Figure 10: **Percentages of bioplastic packagings by applications. Source: IFEU market survey**
(The share of bioplastics in the packaging market in Germany in 2009 was <0.5% and is expected to be 1%-2% in 2011 to 2015)

The biodegradable packagings often contain additives and fossil copolymers. The share of PVOH among the loose fill packagings is about 13% [Würdinger et. al. 2002], and up to 5% of fossil-based additives are added to the cups and bowls that mostly consist of PLA. The bio-based percentage by weight among flexible films is between 30% and 50%, according to the data collected. The fossil share is typically made up of biodegradable co-polyesters such as PBAT.

Forecast

Figure 9 and Figure 10 also contain information about the period from 2011 to 2015. It can be anticipated that the share of bioplastics in the overall plastic packagings market will increase to 1%-2%. This estimate is based on evaluations by packaging manufacturers of their own market potentials in Germany. In addition, market activities that were taking place or announced in 2011 with respect to the use of bio-PE and bio-PET in the production of films and bottles were taken into account. The period from 2011 to 2015 was chosen because the implementation had already started in 2011, and the implementation period anticipated by the market players, as they stated in the interviews, was the next two to four years.

Virtually all packaging manufacturers interviewed were expecting a positive sales development for their packaging products made from bioplastics in this period. One manufacturer stated that he rather focuses on using recycled material from conventional plastics and does not want to develop the bioplastics business proactively.

In addition, the market players provided information on the anticipated overall market development. The greatest increase is expected for carrier bags and shopping bags. But the range was rather wide. Some examples:

- Flexible film products in general: expected increase by 10%
- Bags: expected increase by 50%
- Carrier bags: expected increase by 200%

The anticipated growth also applies to all foamed products but no figures were provided here.

Among the shape-retaining products, a positive sales development is expected, in particular, for beverage bottles (more often made from bio-PET than from PLA), bowls and yogurt pots (both most likely made from PLA). Estimates range from 5% to 25%, but these have to be viewed in the context of the extremely low market volume of 2009.

It should be noted that Danone has introduced various bioplastic packagings into the market in the current year 2011. The PLA amount of yogurt pots (Activia) is 3,000 metric tons. Danone is also in the German market with bio-PET bottles and bio-PE packagings. Coca-Cola is active in the biopackaging segment with bio-PET bottles and will introduce beverages in bio-PET bottles into the German market from mid-August, 2011 [Coca-Cola 2011].

Bio-PE has also been in the German market since 2011 in form of shopping bags (Tengelmann).

Among the various types of bioplastics, continued growth is clearly anticipated for established materials based on starch and PLA. As indicated above, their relative share will decrease as a result of the increasing market presence of packagings made of bio-PE and bio-PET.

The biopackaging manufacturers make very cautious growth forecasts for more established polymers such as fossil biodegradable polyesters and cellulose-based plastics as well as the polyhydroxyalkanoates that have rarely been used as yet. The global capacity development however shows that fossil co-polyesters like PBAT have recently seen capacity increases.

The questionnaire also took into account bio-1,3-propanediol-based polymers and bio-polyamides. These do not appear to matter in the German packaging market of 2009 at all. However, some market players anticipate that this will change.

Bio-PE and bio-PET are made of bio-ethanol that is currently primarily obtained from Brazilian sugar cane. Molasses from India are presumably used as well.

The biogenic portion in bio-PE should be between 85% and 100%. The bottom value refers to bio-PE-LLD, which requires a higher portion of added fossil co-polyesters than bio-PE-LD or bio-PE-HD. Only the monomer monoethylene glycol (MEG) is currently of biogenic origin in bio-PET. Since PET is made from MEG and terephthalic acid (TPA), the biogenic percentage by weight of the finished PET polymer is about 30%. Production capacities for biogenic p-xylol were reported recently (see also Fig. 7). This substance can be used to produce TPA. In the foreseeable future, predominantly or completely biogenic material could enter the market.

The activities aimed at introducing bioplastic packagings for brand-name products could give a major push to the German market for bioplastic packagings. The estimated share of bioplastic packagings of 1% to 2% for the next few years could be higher. All in all, the potential extent of such a market impulse cannot be reliably quantified.

EUWID 28.2011 references a current market study by the Frost & Sullivan market research institute, according to which the European market for bioplastic packagings is to increase from 142.8 million euros in 2009 to 475.5 million euros by 2016. This would mean that the market volume will triple and be in the order of magnitude of the volume increase estimated for the German market in the same period.

Classification of bioplastics in the packaging market

This Section summarizes the information provided in the previous chapters and sections and gives an overview of the structure of the bio-packaging market.

The following classification appears useful based on Figure 4 for the bioplastics currently used in the German packaging sector:

- Starch-based blends (starch blends)
- PLA-based blends
- Bioplastics made from thermoplastic starch (TPS)
- Bioplastics made from PLA (PLA)
- Cellulose-based plastics (cellulose)
- Bio-based bioplastics (bio-PE, bio-PET)

The bio-based portion in the first two groups is typically combined with a biodegradable, fossil material component. This allows targeted setting of specific technical processing and application characteristics.

The following biodegradable fossil polymers are relevant for the packaging sector:

- Polybutylene adipate terephthalate (PBAT)
- Polyvinyl alcohol (PVOH)
- Polycaprolactone (PCL)

The bioplastic types mentioned will be assigned to individual packaging applications below. The following groups are considered relevant:

- Beverage bottles (without milk-based beverages) Bio-PET

  (conventional fossil polymer: PET)
- Beverage bottles for milk-based beverages Bio-PET, PE-HD

  (conventional fossil polymers: PET, PE-HD)
- Cups, bowls: PLA, in the future also bio-PET

  (conventional fossil polymers: PP, PET, PS)
- Flexible film products: Starch- and PLA-based co-polyesters;

  Cellulose-based polymers

  (conventional fossil polymers: PE-LLD, PE-LD, PE-HD, PP)
- Foamed packagings: foamed starch-based co-polymers

  (conventional fossil polymer: PS-E [expanded polystyrene])

It may be relevant, particularly for the ecological evaluation, which biomass is used, how it is processed, and from which region it originates. This aspect was taken into account in the literature analysis and documented separately in the brief specifications.

Table 1 gives examples of the connection between bioplastics and the basic or biomass raw materials used.

Table 1: Overview of established biodegradable plastics and manufacturer as per August 2009

Raw material	Base material	Plastic	Manufacturer
Starch, sugar	e.g. glucose	PHB/PHV	Biomer; Metabolix; PHB Industrial S/A
Maize starch	Lactic acid	Polylactide (PLA)	Nature Works; Synbra Technology; FKuR Kunststoff GmbH
Potato, wheat, maize	Starch	Thermoplastic starch or starch blends	Novamont; Biotec GmbH; BIOP; Rodenburg Biopolymers; Plantic Technologies (DuPont)
Wood	Cellulose	Cellulose film	Eastman; Innovia Films; FKuR Kunststoff GmbH
		Degradable polyesters	BASF SE

Source: [UBA 2009]

The stages of the value chain shown here can overlap in reality. The manufacturers named in Table 1 may be at different positions in the processing chains. For example, NatureWorks only deals with the manufacture of PLA from starch-containing raw materials (currently maize), while further processing into blends or transformation, respectively, is performed by other companies. Novamont is involved in both the production of the biodegradable plastics and the production of the most varied blends. The strengths of companies such as Novamont or FKuR lie in the manufacture of processable compounds.

Finally, Figure 11 shows the bioplastic classification as far as it is deemed relevant for the packaging sector. The bioplastics or monomers printed in italics were not yet available in the market when this report was completed.

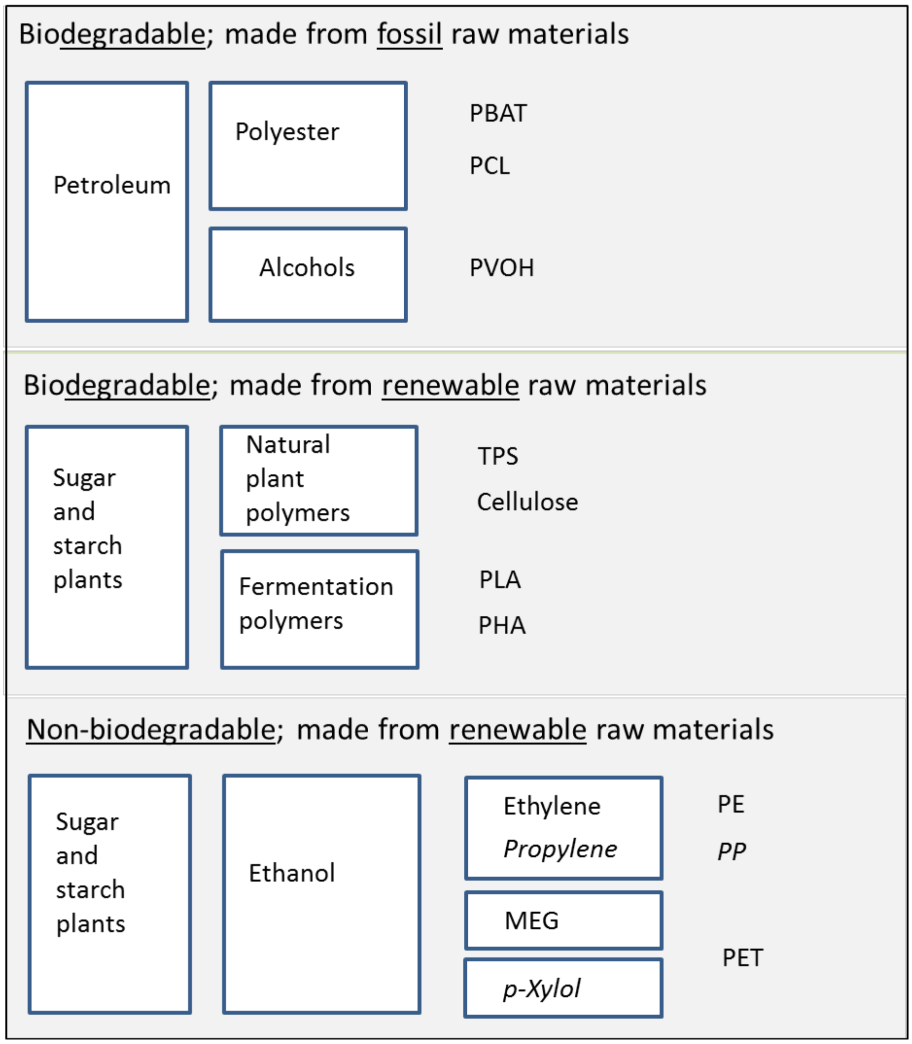

Figure 11: Classification of bioplastics in the packaging sector, adapted based on [UBA 2009]

2.4 Disposal situation

According to Consultic, the volume of plastic packaging waste was 2459 metric kilotons in Germany in 2009 [Consultic2010]. This is the volume of all plastic packaging waste in Germany, not just the waste incurred by private end consumers but also the waste incurred by commercial end users. Energy recovery is predominant among the disposal routes with a share of 55%. It includes waste incineration with energy recovery. Mechanical recycling reaches 42% (Figure 12).

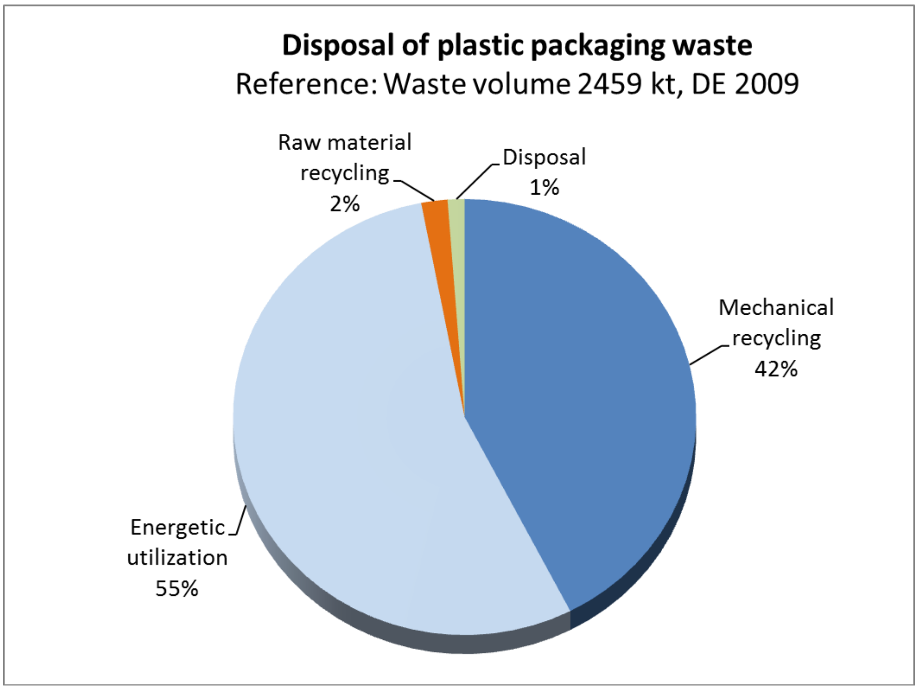

Figure 12: Disposal of plastic waste

Source: [Consultic 2010]

This shows that only highly aggregated data is available even for established plastic packagings. In addition, no difference is made between conventional plastics and bioplastics.

We contacted the following associations and companies to obtain information about the volume flow in the field of disposal.

- Bundesverband Sekundärrohstoffe und Entsorgung e.V. (Federal Association for Secondary Raw Materials and Waste Disposal; BVSE)
- Bundesgütegemeinschaft Kompost e. V. (Federal Quality Association for Compost, reg. assoc.)
- Duales System Interseroh SE (Interseroh Dual System)
- Bundesverband der Deutschen Entsorgungs-, Wasser- und Rohstoffwirtschaft e.V. (Federal Association of the German Waste, Water and Raw Materials Management Industry, reg. assoc.; BDE)
- Duales System Deutschland GmbH

We asked for the following information:

- What are the quantities and packaging types that enter composting or fermenting via household waste? Differentiated by:
  - Industrial composting
  - Home composting
  - Fermentation
- What quantities and packaging types enter composting or fermenting through special activities? Differentiated by:

  - Events
  - Other?
- What quantities and packaging types are disposed into the yellow bag?
  - And from there: enter which sorting fractions?
- What quantities and packaging types are disposed in the regular waste?
- General position regarding biodegradable plastic packagings

The questions on disposal were also included in the questionnaires that were sent to the manufacturers of bioplastics and packaging manufacturers.

The three recipients listed first above provided specific information. It became clear that quantitative statements were hardly made or could hardly be made. Only BVSE provided an assessment of the relative relevance of individual disposal routes for bioplastic packagings (see below).

The costs for bioplastics for packaging purposes are still higher than the costs for conventional packaging plastics. It can therefore be expected that they will primarily be used where an additional benefit such as a positive marketing effect can be achieved. We will therefore assume for further considerations that bioplastic packagings are mainly used as primary packaging of products intended for private end consumers. This also coincides with the statements made by the market participants interviewed. Only biodegradable loose fill chips and air bubble films can also incur in wholesale trade, especially when they are used as transport packagings.

Bioplastic packaging waste is therefore mainly incurred in private households. It is either thrown into the recycling bag, regular waste, or biowaste. As discussed above, there were predominantly flexible films and loose fill packagings as well as a smaller portion of semi-rigid cups and bowls in use in 2009. End consumers can hardly distinguish these products by their shape and appearance from similar conventional plastic products.

Some packagings bear a logo indicating their compostability. A consumer could distinguish these when taking a closer look. We assume that special handling of bioplastic packagings by consumers can be found for biodegradable bags that are also used for collecting biowaste. It can be expected that these will be thrown into the green bin together with their contents. According to the data available to us, biodegradable trash bags did not make up more than 10% of the market for bioplastic films in 2009.

Further considerations on disposal routes for bioplastic packagings are based on the premise that consumers treat these mostly like they treat conventional plastic packagings.

The result of these considerations is shown in the form of a simplified material flow chart in Figure 13. This flow chart is also based on information from [HTP-IFEU 2001], [Cyclos-http 2011], [Kauertz et. al. 2011], and [Christiani 2011]. The flow chart represents the disposal routes for bioplastic packagings of the flexible films and cups/bowls application groups. It will be explained in more detail below.

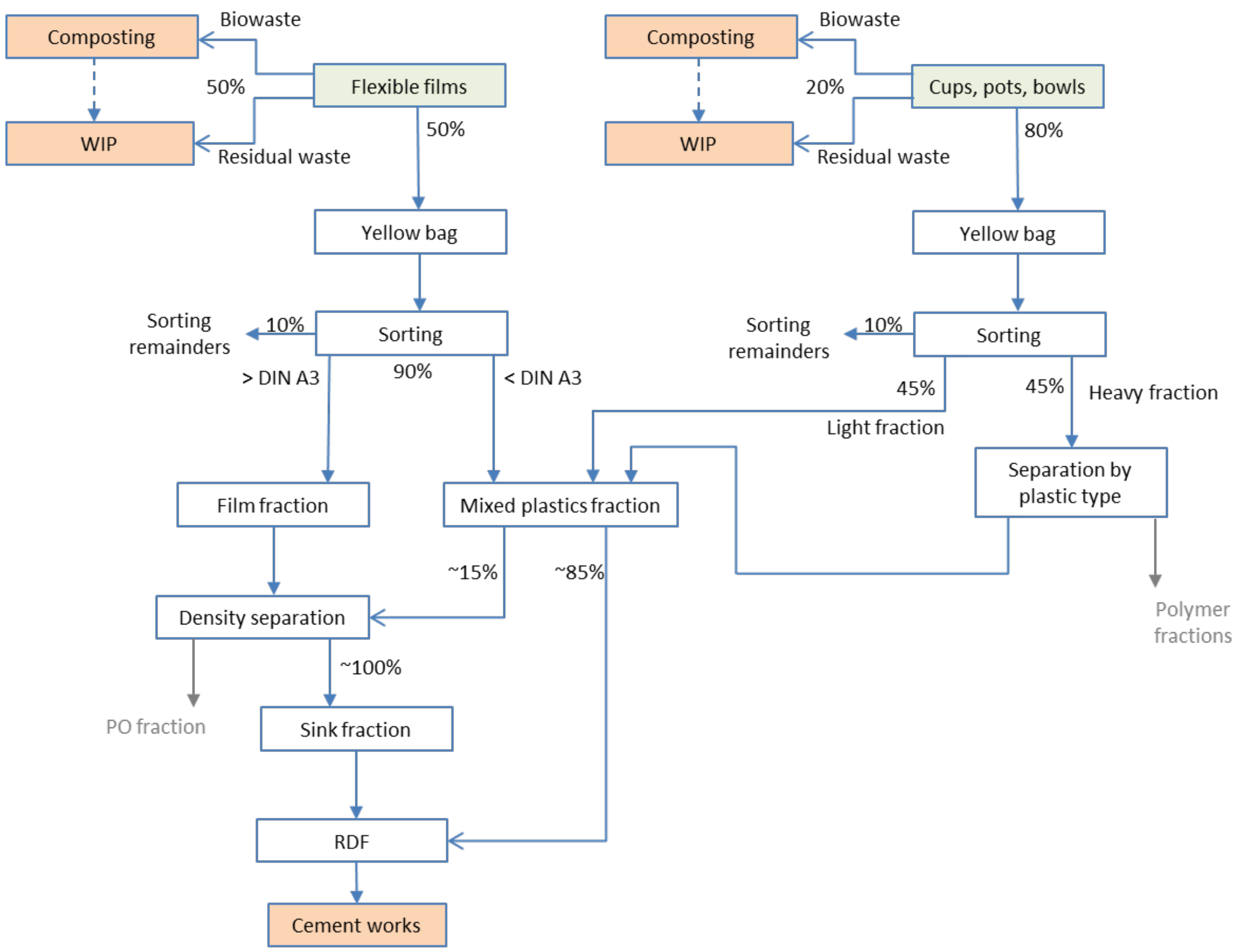

Figure 13: Disposal routes of bioplastic packagings

Source: IFEU evaluation derived from [HTP-IFEU 2001], [Cyclos-HTP 2011], [Kauertz et. al. 2011], and [Christiani 2011] (reference: Germany, 2009)

The first question to be asked is which collection fraction the packagings will end up in. We assume that 50% of the flexible films and 80% of cups/bowls are thrown into the yellow (recycling) bag. These figures were obtained based on the specific collection quota for packaging materials or item groups according to [HTP-IFEU 2001, Fig.2.2.1], and [Kauertz et al. 2011, Fig. 2.2].

The residual amount would then get into waste treatment through WIPs or composting plants; it is hard to estimate the percentages. Eventually, many of the bioplastics collected with the biowaste will be disposed of in an incinerator because they would be sorted out as contaminants by a drum screen before the rotting step in most German composting plants [Wellenreuther et al. 2009b].

The film fraction in the recycling bag will enter various sorting fractions depending on size. Films from a size of about DIN A3 will be sorted into the film fraction. This includes plastic carrier bags/shopping bags, for example. The recycler will subject the film fraction initially to a density separation (sink-float separation) aimed at separating polyolefins from other plastics. The biodegradable plastic films based on starch blends and PLA blends all have a density >1 and enter the sink fraction, which is recycled into a refuse-derived fuel (RDF) in a subsequent step.

Films smaller than DIN A3 enter the mixed plastics fraction. Mixed plastics are also subjected to density separation such that the biodegradable packagings of the mixed plastics fraction are ultimately also recycled into refuse-derived fuel (RDS).

The cups/bowls material group is partly sorted into the light fraction, partly into the heavy fraction. This will on average be a 50-50 division [Christiani 2011]. The light fraction goes directly into the mixed plastics fraction. The heavy fraction passes a separation line where it is sorted by types of plastic. Among bioplastics, only PLA products are assumed to have been in the heavy fraction in 2009. The sorting plants have so far been designed to select PET, PP, PE, and PS. The PLA products may have ended up in the residual mixed plastics fraction or in sorting remainders. Loose fill materials should be found in the light fraction and will therefore also be recycled in the mixed plastics fraction.

It can therefore be assumed that used bioplastic packagings were largely recycled into refuse-derived fuel together with conventional plastics and ultimately utilized energetically in cement works. Most of the other waste from bioplastic packagings was incinerated, either as part of the sorting remainders from waste-sorting plants, directly from residual waste, or from contaminant screening of composting plants.

The disposal situation as outlined here is somewhat in contrast to the evaluation by BVSE who assume the following division: 20% composting, 10% self-composting, 10% fermentation, 30% yellow (recycling) bag, 30% waste incineration. The percentage for the yellow bag is estimated too low in our opinion. But the division mentioned by BVSE could apply to biodegradable trash bags.

It should be noted with respect to the disposal situation outlined above that, according to DSD GmbH [Kauertz 2011], it is also possible that PLA cups are not detected as plastics in the heavy fraction due to the current state of the sorting equipment and do not end up in the mixed plastic fraction but among the sorting remainders. Further disposal would then proceed via a WIP rather than by energy recovery in the form of RDF.

As can be seen from the explanations above, knowledge about the disposal situation of bioplastic packagings is very limited. There are substantially two reasons for that. First, access to consistent data covering the national waste flows has become more difficult since Duales System Deutschland GmbH was broken up because no central documentation of volume flows is kept any more. Second, the data collected by the various operators of the dual system that have existed since on the composition of the waste collected in the yellow recycling bag is focused on the material groups that are relevant to meet collection quota. Bioplastic packagings are not documented separately.

In general, the question is if and how access to such information will be possible in the future. In the current competitive situation, willingness of dual system operators to make such data publicly available at the level of detail needed has waned.

As outlined above, used packagings are sorted with the goal to obtain sort-specific fractions that are as homogeneous as possible. In this respect, bioplastics are currently treated like contaminants and enter either the sorting remainders or the mixed plastics fraction. The latter serves as a collection group for those plastics that cannot be positively screened into a type-specific target fraction. It has also been pointed out repeatedly that bioplastics can interfere with the mechanical recycling of the type-specific fractions.

The reason for such interference lies in the relatively varied melting temperatures of bioplastic packagings, which frequently are below those of conventional plastics. They can enter the product during melting filtration and cause functional defects in the processing or use of the product.

Despite the sorting and separating steps mentioned, it is possible that small quantities of bioplastics enter the type-specific target fractions. For example, the selectivity of density separation is not 100%. Selectivity depends on the equipment used and on sufficient size of the plant. These systems are typically somewhat undersized in real-life plants due to cost reasons. It is therefore quite possible that bioplastics are sorted into the light fraction[10].

The current disposal options for bioplastic packagings described above lead to considerations regarding the further development in the years to come. Three groups of bioplastic packagings would have to be distinguished:

A. Applications of the same material as conventional plastics, primarily made of bio-PE, bio-PP, and bio-PET
B. Biodegradable packagings or packaging components made of mono-materials, primarily PLA and PHA
C. Biodegradable packagings from material blends, primarily starch-based and PLA-based copolymers as well as cellulose-based multi-layer films.

Groups B and C were developed with the goal of biodegradability and in most cases meet the criterion of compostability according to EN 13432. One could therefore expect that the Packaging Ordinance provision for the development of disposal structures would cause a stronger focus on composting, but this did not happen.

<u>Excursion: Composting</u>

A large-scale test with compostable packagings has been performed in Kassel in 2001 and 2002. Over a dozen products in compostable packagings were sold in various retail shops. Only such packagings were approved that had been tested and certified with respect to compostability, e.g. films based on renewable raw materials, starch-based shopping bags that could also be used as bags for green waste, and carrier bags for fruits and vegetables (www.modellprojekt-kassel.de).

The expectation of the Kassel model was to give an impetus to the market development of biodegradable materials. The sponsors of the project considered the popularity of this material class increased due to the model project. A study of the collection of biodegradable materials in the green bin did not reveal a significant change in biowaste quality. The biodegradable packagings did not interfere with the rotting process.

In the 1990s, an optimized method for the separate collection of green waste was developed in Italy that is also called the Italian system. According to Novamont[11], this model is characterized “by higher collection rates, less missorts, and lower cost”. The waste is collected in biodegradable trash bags.

According to Novamont, “several years of experience gained by the waste disposers” have shown that “the people participate actively in this system, both in quantitative and in qualitative respect, if collection is made

[10] This aspect is being studied in an ongoing EU research project with the participation of Hannover University of Applied Sciences and HTP [Christiani 2011]

[11] http://www.novamont.com/default.asp?id=640

as easy as possible for them by hauling away the waste taken to the curb at regular and shorter intervals. The composting plants can frequently omit mechanical pre-screening of the bio-waste”. The biodegradable trash bags are composted together with the bio-waste.

Numerous composting plants work with downstream screening in the Netherlands [Schnarr 2011]. This indicates that mechanical pre-treatment for sorting out plastics is not necessarily required.

According to the current version of the German Biowaste Ordinance, biodegradable materials are accepted as suitable waste for separate collection and recycling in bio-waste treatment plants if they are fully bio-based only. The draft amendment of the Bio-Waste Ordinance modifies this provision by also listing biodegradable materials that are predominantly made from renewable raw materials as permissible bio-waste. This is to ensure “unobstructed access to bio-waste collection systems throughout Germany” [BMELV 2009] for bioplastic waste and bio-waste bags certified as compostable in accordance with the action plan of the Federal Government.

The above examples show, on the one hand, that disposal of biodegradable packagings or trash bags would be possible on the bio-waste route. But all examples mentioned also show that this requires a targeted information effort on the part of, or including, the communities to prevent undesirable increased contamination of the bio-waste with non-biodegradable plastics. That would mean a considerable financial and time expenditure. Since the regional administrative bodies responsible for disposal have some freedom regarding the design of their waste collection systems, an additional coordination effort would be required to achieve far-reaching or even national implementation.

Excursion: Fermentation

According to [Grundmann and Wonschik 2011], public waste disposal entities in some disposal regions in Germany offer, or recommend the use of, bio-waste bags made of biodegradable plastics, but this almost exclusively occurred in disposal regions with aerobic bio-waste utilization. It can further be assumed according to [Grundmann and Wonschik 2011] that “bio-waste will increasingly be utilized in fermentation plants or in composting plants with an upstream fermentation step”.

There is hardly any information available on the behaviour of biodegradable plastics in fermentation plants. Tests of hydrolysis and anaerobic co-fermentation of various biodegradable plastics have recently been performed at Dresden Technical University. Mater-Bi, a TPS-based bioplastic, and Bio-Flex, a PLA-based bioplastic, were used [Grundmann and Wonschik 2011].

These tests indicate that thermophilic conditions are required for fermenting the bioplastics studied. Hydrolysis at temperatures between 60°C to 70°C was performed as a preliminary step in the tests. The maximum degradation rate was 20%.

The results show that the fermentation of bioplastics is in a considerable need for optimization. Potential problems, especially when co-fermenting film products, have to be taken into account because these may cause faults due to wrapping around pump and stirrer units. An upstream hydrolysis could help to avoid these problems.

While there are European test standards and composting marks based on them, there are none with respect to the anaerobic treatment of bioplastics.

3 Survey of opinions on the existing special regulation for biodegradable plastic packagings in the Packaging Ordinance

The poll of the market players was to provide a survey of opinions with respect to the treatment of biodegradable plastics in the Packaging Ordinance. The three options listed below were used as key questions:

A. Extension of the existing special regulations

B. Complete abolition of the existing special regulations

C. Modification and adaptation of the existing regulations to account for current or foreseeable future developments

The key questions were supplemented by detailed questions, e.g. with respect to the type of desired incentives. Another aspect that was taken into account was based on the observation that the focus of marketing bioplastics is increasingly shifting from biodegradability towards “bio-basedness”, i.e. use of renewable raw materials (see, for example, [Danone 2011]).

We will distinguish two groups of players below, whose views may differ widely:

a. The manufacturers of plastics and bioplastics as well as bioplastic packagings

b. The disposers

3.1 Manufacturers of bioplastics and bioplastic packagings

The manufacturers assume that bioplastic packagings will mainly be thrown into the yellow recycling bag and a part of them will be incinerated. But these are mere assumptions. The manufacturers do not have any empirical data about that. Therefore, they cannot provide information on the potential further utilization of bioplastic packagings as a “material component” via the yellow bag.

Criticism is raised in this context regarding “unspecified disposal classification” and that “there is no unambiguous legal framework regulating the disposal of bioplastic packagings”. One point that results from these responses is that compostability of the bioplastic packagings has been an essential market criterion, perhaps even the most important selling point (quote: “Consumers in Germany are responsive to the term 'biodegradable'“). Almost all bioplastic packagings in the German market display the “tested by DIN CERTCO” compostability mark.

But there is also the impression that bioplastic packagings do not have access to the German composting systems (quote: “a big constraint was that there was no access to the German composting systems”). Manufacturers also point out that “end consumers cannot separate (note: probably meant as 'differentiate') regular plastics and bioplastics”.

Overall, all manufacturers who responded wish an extension or modification/adaptation of the special regulation. It is almost unanimously expected that the special regulation is to help compensate the existing price difference, like it did before.

However, the previous regulation did not seem to apply to most products (such as yogurt pots, packaging films and foils). Nine manufacturers said that their products did not benefit from the special regulation. One manufacturer said expressly that “it was definitely helpful for carrier and shopping bags”. All in all, the feedback from manufacturers and users of bags (shopping bags, fruit bags) was positive. The special regulation appears to be utilized without problems for these applications.

One reason provided for it not being applicable was that the special regulation was too restrictive because the entire packaging (i.e. the pot or cup and the foil for closing it) had to be made of biodegradable materials. It is difficult to produce packagings completely from biodegradable materials if they are to meet the usual industrial standards. One example was Danone's PLA pot that has a lidding film which consists of a non-biodegradable plastic composite film.

One manufacturer was highly critical and said the existing special regulation “was thrown into the market without any mentionable coordination with, or consent from” industrial partners.

A number of manufacturers do not rate the criterion of “biodegradability” or “compostability” very highly. It would only make sense for specific applications (such as fast food restaurants or university cafeterias) or bio-waste bags, but only if subsequent composting could be ensured. Statements by the European associations PlasticsEurope and EuPC made in a position paper from 2009 [PlasticsEurope and EuPC 2009] point in the same direction; the position paper names the following fields of application as useful for compostable bioplastic products in the packaging sector:

- Composting of food packagings together with their contents
- Compostable catering products
- Compostable bio-waste bags.

The paper also says that biodegradable plastic products are no solution for littering, which is a behavioural problem.

Some manufacturers thought that the criterion of biodegradability had value attached to it, since it was an important feature for differentiation or recognition by users and consumers of this material group. In addition, biodegradability had and has an important functional significance in major European markets (in particular, the U.K., Italy, France) for waste management and prevention of littering.

The industry sees a clear trend towards plastics that are mostly or fully made from biomass. Some manufacturers think that the special regulation in the Packaging Ordinance should in the future be aimed at “bio-based, not biodegradable plastics”. One manufacturer even demanded “promotion based on carbon footprint or energy consumption”. Some think that the regulation should be changed to give equal value to “bio-basedness” and “biodegradability”.

One manufacturer demanded that a future special regulation should be under the auspices of the EU lead market initiative for bio-based products or refer to the same.

The industrial associations PlasticsEurope, Industrievereinigung Kunststoffverpackungen (IK), and European Bioplastics (EuBP) were also asked for their opinion. The responses received are provided in full in Appendix I. All three associations agree that the special regulation is mainly a signal of political support for the industry but was not able to move much in the market and has therefore not led to a market breakthrough of bioplastic packagings.

The high price of bioplastics has to be seen as a major obstacle. In addition, reasons such as lacking availability (PlasticsEurope and IK) and an often insufficient performance profile (IK) compared to conventional plastics were brought forward.

PlasticsEurope and EuBP point to the lack of harmonization of the legal framework. The existing special regulation of the Packaging Ordinance is aimed at biodegradable packagings certified as compostable while the existing Biowaste Ordinance additionally requires full bio-basedness. This means that a major part of the bioplastic packagings in the market in 2009 was not approved for disposal in the bio-waste bin. The revised version of the Biowaste Ordinance could remedy this in the opinion of both associations.

All three associations again agree about the trend towards bio-based plastics.

The views of PlasticsEurope and IK differ considerably from that of EuBP when it comes to the further handling of the special regulation. The two former associations are in favour of abolishing the special regulation. Especially the fact that the existing regulation starts at the end of the life cycle of the packagings is not seen as guiding to the target. Instead, instruments such as the promotion of innovations should be applied.

EuBP advocates a modification of the existing regulation. One reason they provided is that the trend towards introducing bio-based, non-compostable packagings into the German market could not be foreseen when the special regulation was adopted. Bioplastic packagings are no longer aimed at composting alone.

In the opinion of EuBP, the Packaging Ordinance is an important element of an overall strategy for the promotion of bioplastic packagings that should be pursued to “promote the use of renewable raw materials, climate protection, conservation of fossil resources, and improved recycling and cascaded utilization”. Other support mechanisms should be explored as well. Examples could be an innovation bonus or a bonus for renewable raw materials used for energy recovery (e.g. in the context of the EEC).

3.2 Disposers

Information from BVSE, Bundesgütegemeinschaft Kompost (BGK), and Interseroh is available in this area. The feedback from DSD GmbH and BDE was to the effect that there was no information on market volumes and disposal volumes of bioplastic packagings; they also did not provide input for the survey of opinions.

BVSE and BGK designate all quantities that are thrown into the yellow bag or bio-waste bin as “missorts” because they “obstruct disposal and recycling” [BVSE 2009], [BGK 2009a,b].

In the opinion of BGK, disposal via a bio-waste bin was useful only if the collection is coordinated with the community where the receiving composting plant is located (pre-sorting specifications are limited here to compostable film bags for bio-waste bins or for pre-sorting containers). Utilization was possible in principle but the materials were virtually completely decomposed so that there is no mentionable benefit for the composts produced. There was also criticism because typical rotting times in reality are often shorter than 12 weeks, the period for which biodegradability was tested. It was possible that packaging components are not fully degraded.

In the opinion of BVSE, the special regulation (“unfortunately”) contributed to improved competitiveness of bio-packagings. An extension of the special regulation would not be welcomed.

In the opinion of Interseroh, biodegradable packagings are particularly useful for bags; these should be envisaged as target applications. The recycling potential of these applications was limited, and they were therefore suitable for recycling through composting. The following conditions had to be met:

1. Acknowledgment of composting in the material recovery rates in the Packaging Ordinance (this was possible in accordance with the European Directive on Packaging and Packaging Waste)
2. Far-reaching introduction of biodegradable bags of all kinds. This would virtually eliminate missorts by private end consumers.
3. An associated marketing and information policy.

The advantage would be that the collection and sorting expenditure of the dual systems and the associated costs could be saved. But this would also result in elimination of the energy credit from waste incineration and use as refuse-derived fuel.

Interseroh pointed out that there had been wide coverage of the special regulation in the press (e.g. EUWID). In addition, information can be obtained from the industrial association European Bioplastics. In the opinion of Interseroh, there should be no more information deficits among market participants.

One supplementary hint at the end of this chapter: Two manufacturers of films indicated they knew from life cycle assessments that film products (e.g. bags) from recycled material (versus primary material and bioplastics) provided the best environmental results. It should be considered if packagings should not be granted some financial support based on their content of recycled material. The costs saved could be used for the further development of separation and recycling technologies. The latter could be required if the percentage of bioplastics in the respective waste volume flows were to increase.

4 Ecological evaluation

4.1 Methodology of the literature research

The ecological evaluation of packagings made of bioplastics is at the focus of the research project. The goal is to make reliable statements about the ecological significance of bioplastics as compared to conventional plastics used in packaging. In particular, existing comparative life cycle assessments will be analysed.

See the Excel table in Appendix V for details on the literature research, e.g. key words used for literature search and data sources and an overview of the findings. The literature searched is also listed there. The literature was analysed in two steps:

A. Basic analysis
B. In-depth analysis

The basic analysis was performed for the complete literature searched (see Appendix V). A selection was made for the in-depth analysis.

A. Basic analysis

It was necessary to enter the data material into a uniform grid to enhance clarity and comparability of the relative wealth of information. The documents collected were listed in tables based on uniform criteria. Grouping in the basic analysis was based on the following features:

- Bibliographical data
    - Title
    - Authors
    - Sponsor, if applicable
    - Year of publication
- Subject matter
    - Packaging applications
    - Types of plastics
    - Raw materials
- Study objective
- Functional unit
- Information on ISO conformity
- Selection status (suitable/not suitable for the purpose of the research project)

Some of the selected studies differ considerably in their depth of detail, the impact categories studied, and the life cycle under review. They were therefore assigned to groups in the basic analysis.

1. **Full life cycle assessment studies:** This refers to studies that consider the entire life cycle and several relevant impact categories. Within this group, we differentiate between:
   a. Studies with ISO conformity certificate
   b. Studies without ISO conformity certificate

2. **Studies that include partial life cycle assessments only: Typical studies in this group would be**
   a. Studies on a partial life cycle, e.g. “from cradle to pellet”
   b. Studies with a reduced impact assessment. Quite often, studies were and are performed that focus on greenhouse gases and fossil resources only.
   c. Life cycle inventory studies; these studies focus on energy balancing, supplemented by specific emission parameters

3. **LCA-based information:** This group refers to types of reports that are based on life cycle analyses but document these in a highly condensed or reduced form only.
   a. Environmental Product Declaration (which Novamont likes to use)
   b. Specialist articles

4. **Metastudies and overviews:** This group refers to types of reports that are aimed at evaluating existing studies or the LCAs of many products in parallel. We further distinguish:
   a. Studies aimed at giving an overview of existing studies (“reviews”)
   b. Studies that perform a highly simplified LCA to take into account as many products as possible

We found a total of 85 life cycle studies/studies/specialist articles in our literature search that were subjected to a basic analysis. The collected literature is listed in Appendix V.

B. In-depth analysis

Studies that were of particular interest for the purposes of the research project in the opinion of the contractors were analysed in depth. See Chapter 4.3 for an overview and analysis of these studies. A total of 19 studies were included in the assessment.

The relevance of these studies for the research project was determined based on one or more significant aspects. Important selection criteria were geographic reference to Germany and relevance to the current situation. Studies published before 2005 were included only if they studied a topic, a material, or a process technology that has not been investigated in more recent studies and were found to be relevant for the research project. The highest priority in the selection process was given to studies that looked into full life cycles of packaging systems and met the criterion of ISO conformity.

<u>Selected studies</u>

Studies with ISO conformity certificate

- [Kauertz et al. 2011] "LCA Activia-Becher" [LCA Activia Pots] ; use and bioplastics under review: Yogurt pots made of PLA
- [Binder and Woods 2009] Comparative Life Cycle Assessment of Drinking Cups; use and bioplastics under review: Drinking cups made of PLA
- [Wellenreuther et al. 2009a] "Life Cycle Assessment of Waste Bags"; use and bioplastics under review: Waste bags made of Biopar (starch + 49% PBAT) or of Evocio (PLA + 68% PBAT)
- [Murphy et al. 2008] "Life Cycle Assessment (LCA) of Biopolymers for single-use Carrier Bags"; use and bioplastics under review: Carrier bags made of Mater-Bi (50% starch, 50% polycaprolactone) or of PLA + Ecofoil (fossil-based biodegradable bioplastic)
- [Ovam 2006] "Comparative LCA of 4 types of drinking cups used at events"; use and bioplastics under review: Drinking cups made of PLA (one-way)
- [Detzel and Krüger 2006] "Life Cycle Assessment of Polylactide (PLA) - A comparison of food packaging made from NatureWorks® PLA and alternative materials"; use and bioplastics under review: Hinged bowls made of PLA
- [Würdinger et al. 2002] "Kunststoffe aus nachwachsenden Rohstoffen – vergleichende Ökobilanz für Loose-Fill-Packmittel aus Stärke bzw. aus Polystyrol"; [Plastics made of renewable raw materials – a comparative life cycle analysis of loose-fill packagings made of starch or polystyrene] use and bioplastics under review: Loose fill material made of starch
- [Razza et al. 2008] "Compostable cutlery and waste management: An LCA approach"; use and bioplastics under review: Cutlery made of Mater-Bi

ISO-oriented studies without ISO conformity certificate

- [Hermann 2010] "Twisting biomaterials around your little finger: environmental impacts of bio-based wrappings"; use and bioplastics under review: laminated packaging films made of various bioplastics such as PLA, metallized PLA, bio-PE, paper laminates, for example with bio-based polyester (BBP) or ethylvinyl acetate (EVA)
- [Madival et al. 2009] "Assessment of the environmental profile of PLA, PET and PS Klappschale containers using LCA methodology"; use and bioplastics under review: Hinged bowls made of PLA
- [Liptow und Tillman 2009] "Comparative life cycle assessment of polyethylene based on sugarcane and crude oil"; use and bioplastics under review: Bio-PE polymer
- [Pladerer et al. 2008] Vergleichende Ökobilanz verschiedener Bechersysteme beim Getränkeausschank an Veranstaltungen [Comparative life cycle assessment of various cup systems for beverage service at events]
- [Chaffee et al. 2007] "Life Cycle Assessment for Three Types of Grocery Bags"; use and bioplastics under review: Carrier bags made of a mixture of 65% EcoFlex®(fossil-based biodegradable bioplastic), 10% polylactic acid (PLA), and 25% calcium carbonate

Studies that include partial life cycle assessments only:

A. “Cradle to pellet” studies[12]

- [Groot and Boren 2010] “Life cycle assessment of the manufacture of lactide and PLA biopolymers from sugarcane in Thailand”; use and bioplastics under review: Lactides and PLA

B. Studies with a reduced impact assessment.

- [Kurdikar et al. 2002] “Greenhouse Gas Profile of a Plastic Material Derived from a Genetically Modified Plant”; use and bioplastics under review: PHA polymer

Life cycle inventory studies

- [Garrain et al. 2007] “LCA of biodegradable multilayer film from biopolymers”; use and bioplastics under review: Multi-layer films of PLA and starch blend
- [Bohlmann 2004]: “Biodegredable Packaging Life Cycle Assessment”; use and bioplastics under review: Yogurt pots made of PLA

Metastudies and overviews

- [Shen and Patel 2008]: “Life Cycle Assessment of Polysaccharides: A Review”; use and bioplastics under review: loose fill made of starch and others
- [Patel et al. 2003a] “Environmental assessment of bio-based polymers and natural fibres”; use and bioplastics under review: Starch-based products, PHA and PLA

4.2 Supplementary LCA overviews

4.2.1 Motivation

Current developments and trends were derived from the market analysis and the survey of opinions on which there is little or no literature so far. This applies to the following innovations in particular:

1. Packaging products made of bio-PE which replace products made of fossil-based PE
2. Packaging products made of bio-PET which replace products made of purely fossil-based PET
3. The announcement or ongoing development of alternative product lines in the manufacture of PLA. This includes the manufacture of PLA from sugar plants or the use of residual materials from agriculture and food production as a raw material for manufacturing PLA.

To be able to make qualified statements on these still rather novel developments, we performed our own supplementary life cycle assessments as part of this research project on the following topics:

1. Comparative LCA of film packagings made of PE-LD and bio-PE

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[12] The [Tabone et al. 2010] reference frequently quoted in newspaper and specialist publications has not been included in this study because it has considerable technical weaknesses and does not provide valid findings. For the major points of criticism regarding this reference, see [Murphy et al. 2011] and [Dale 2011].

2. Comparative LCA of bowls with a hinged lid made of PLA and PS taking into account alternative biomass raw materials for PLA manufacture.

The study was performed in the form of screening life cycle assessments. Real-life specifications were set for the life cycle analyses, but without striving for the depth of detail and scope of documentation of ISO-compliant LCAs. The findings are of an orientational nature.

A review of bio-PET could not be performed within the scope of this study.

4.2.2 Procedure/methodology

We relied on existing material flow models and data available at IFEU or data derived from the literature. The following fundamental specifications are identical for both analyses:

- The scope of the LCA is Germany
- We strived for including as much of the full life cycle of packagings as possible
- The allocation method selected for both LCAs was the parity approach (50% method according to UBA).
- Disposal of recycling products in the second life cycle was taken into account[13].
- The following impact categories and LCA variables were analysed:
    - Climate Change
    - Consumption of Fossil Resources
    - Summer Smog (POCP)
    - Acidification
    - Terrestrial and Aquatic Eutrophication
    - Human Toxicity: Fine Dust (PM10)
    - Land Use: Farmland
    - Cumulative Process Water Consumption
    - Total Cumulative Energy Demand (CED)

The procedure and methodology of the two screening life cycle assessments is briefly described below.

[13] Disposal in the second life cycle means that the issuing system is not only given a material credit for regranulates from recycling but that the issuing system also accepts the burden for the final disposal of the regranulates. For more information on what this can look like, e.g. for bio-based product lines, see [Kauertz et al. 2011].

4.2.3 Comparative LCA of films made of PE-LD and bio-PE

The goal of the screening life cycle assessments performed here is a comparison of two film packagings made of bio-PE based on Brazilian sugar cane and of fossil PE manufactured in Europe. The bio-PE or fossil PE is further processed in Germany.

The functional unit for the LCA comparison is 1 m² of film, corresponding to 30 g of packaging material.

The screening life cycle assessment includes the following life cycle stages:

- Manufacture of the primary materials (bio-PE and PE-LD)
- Transport of the new product to processing
- Manufacture of the film products
- Transport of the film products
- Disposal of the films (WIP)
- Utilization of the films (recycling)
- Allocation of the use of secondary materials and secondary energy from recycling and disposal processes in the form of credits
- Accounting (credit) for the CO2 bound in the bio-PE

Other specifications for the LCA comparison are:

- Film weight: 30 g/ m²
- Collection rate after use: 50% in the yellow bag
- Credit from recycling: Polyolefin with a substitution factor of 0.7
- Credit from disposal: Power and heating energy Germany

Results:

The results can be seen in Figures 14 to 18. The comparative study of films made of bio-PE and fossil PE shows

- a smaller environmental burden from film packagings made of bio-PE based on the indicators:
    - Climate Change
    - Consumption of Fossil Resources and
    - Summer Smog (POCP)
- a higher environmental burden from film packagings made of bio-PE based on the indicators:
    - Acidification Potential
    - Terrestrial Eutrophication
    - Aquatic Eutrophication

- Human Toxicity: Fine Dust (PM10)

The following statements are valid:

- The assessment for most of the impact categories studied is determined by the loads of the life cycle stage of raw material production.
- Other relevant influencing variables are the awarded credits. Since bio-PE and fossil LDPE have the same calorific value, there is no difference in the energy credits awarded. The material credits do not differ because the recycled material is awarded a PO credit in both systems studied.
- The bio-PE also gets a credit for the CO2 bound in the material that the plants have absorbed during their growth phase. This credit is only visible for the Climate Change indicator but contributes considerably to the result of the packaging system made of bio-PE.
- In the Climate Change indicator, CO2 emissions from the disposal of the packaging system visibly contribute to the LCA result of the packagings studied.
- Loads from the transport of the new product stage make a visible contribution to the result of the bio-PE system in the Acidification Potential, Terrestrial Eutrophication, and Human Toxicity impact categories. These loads are due to NOx, SOx, and PM10 emissions caused by transporting the material by sea vessel and lorry from Brazil to Germany.

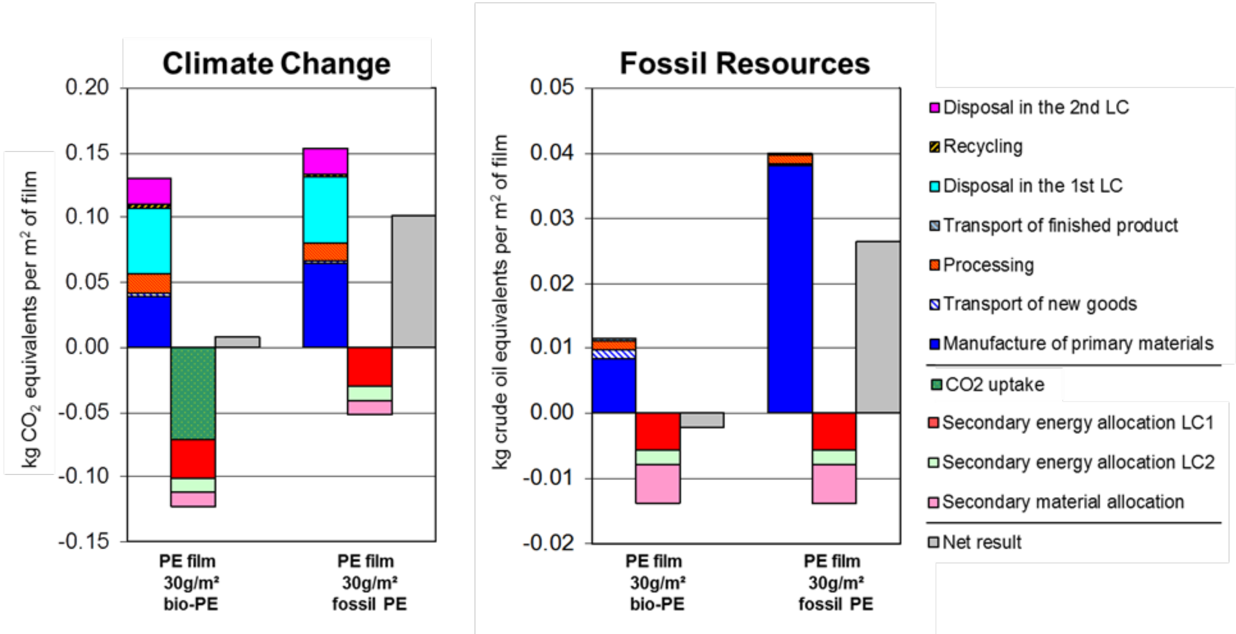

Figure 14: Comparative LCA of film packagings made of fossil PE and bio-PE (Results for the Climate Change and Consumption of Fossil Resources indicators)

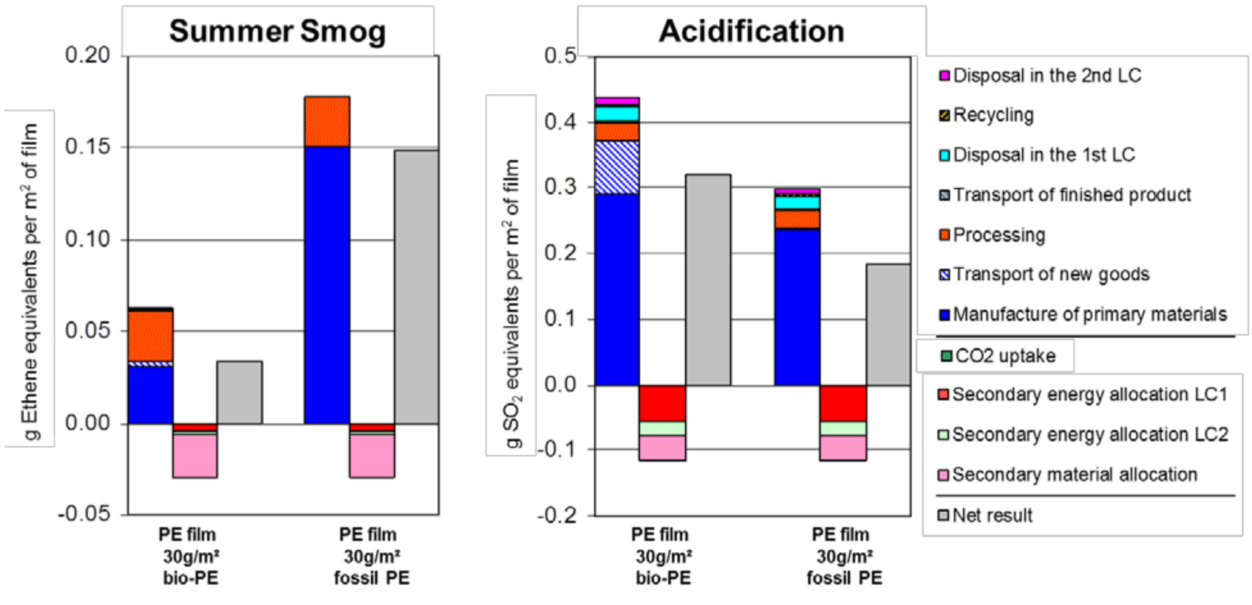

Figure 15: Comparative LCA of film packagings made of fossil PE and bio-PE (Results for the Summer Smog (POCP) and Acidification indicators)

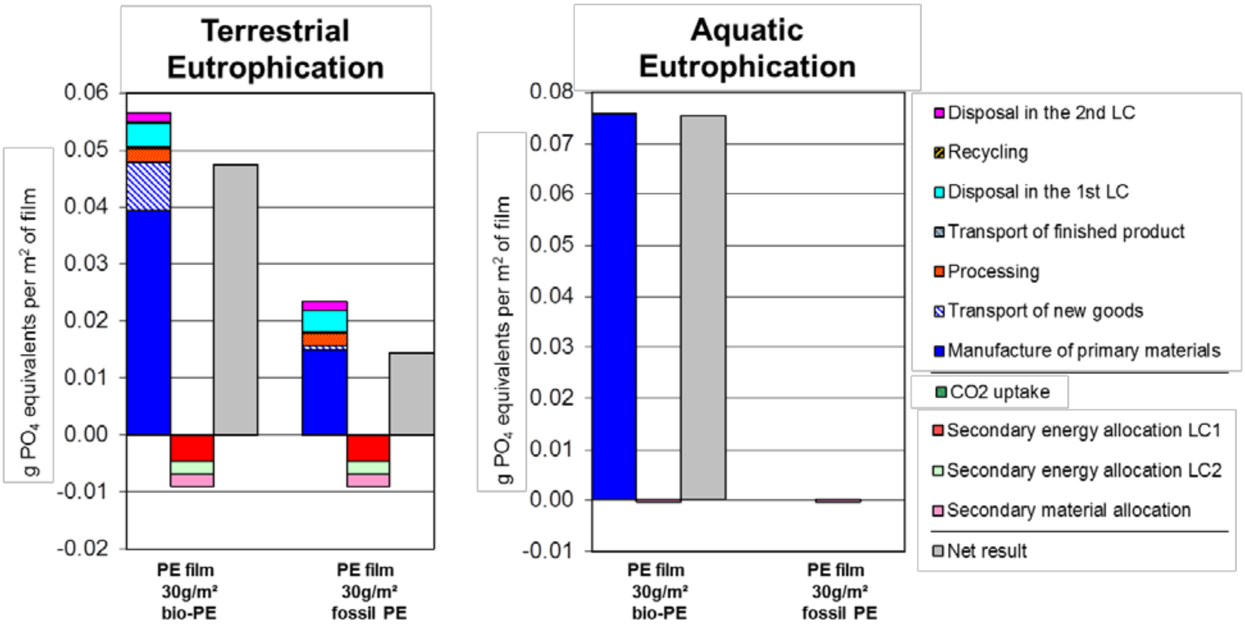

Figure 16: Comparative LCA of film packagings made of fossil PE and bio-PE (Results for the Terrestrial and Aquatic Eutrophication indicator)

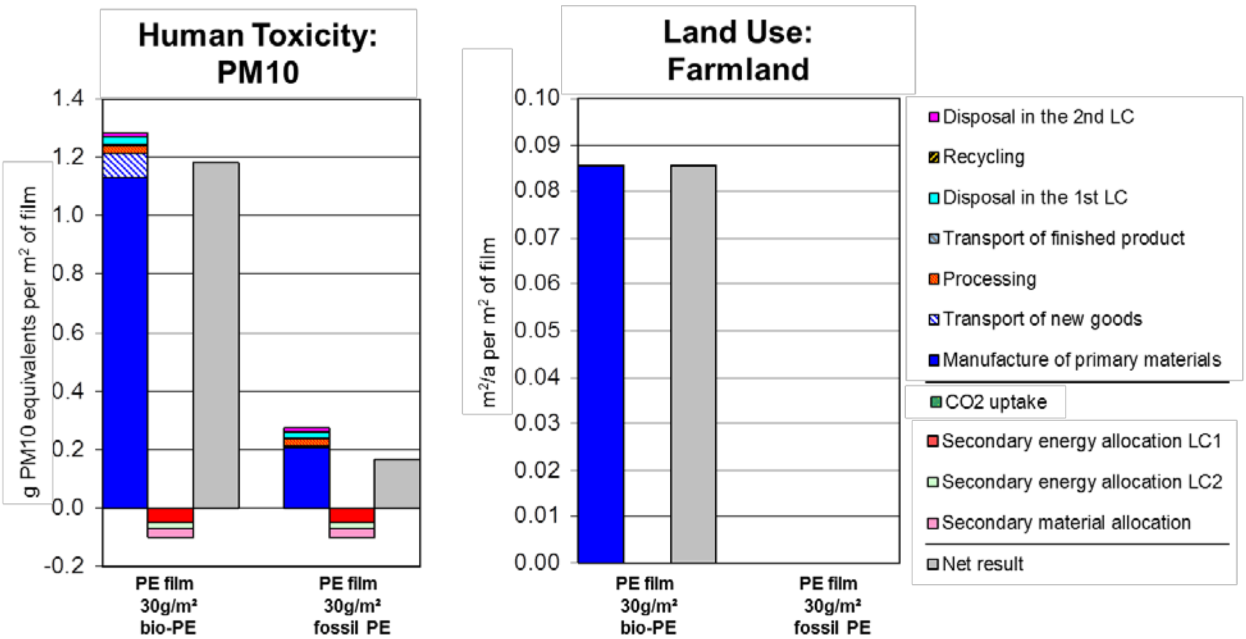

Figure 17: Comparative LCA of film packagings made of fossil PE and bio-PE (Results for the Human Toxicity: PM10 and Land Use: Farmland indicators)

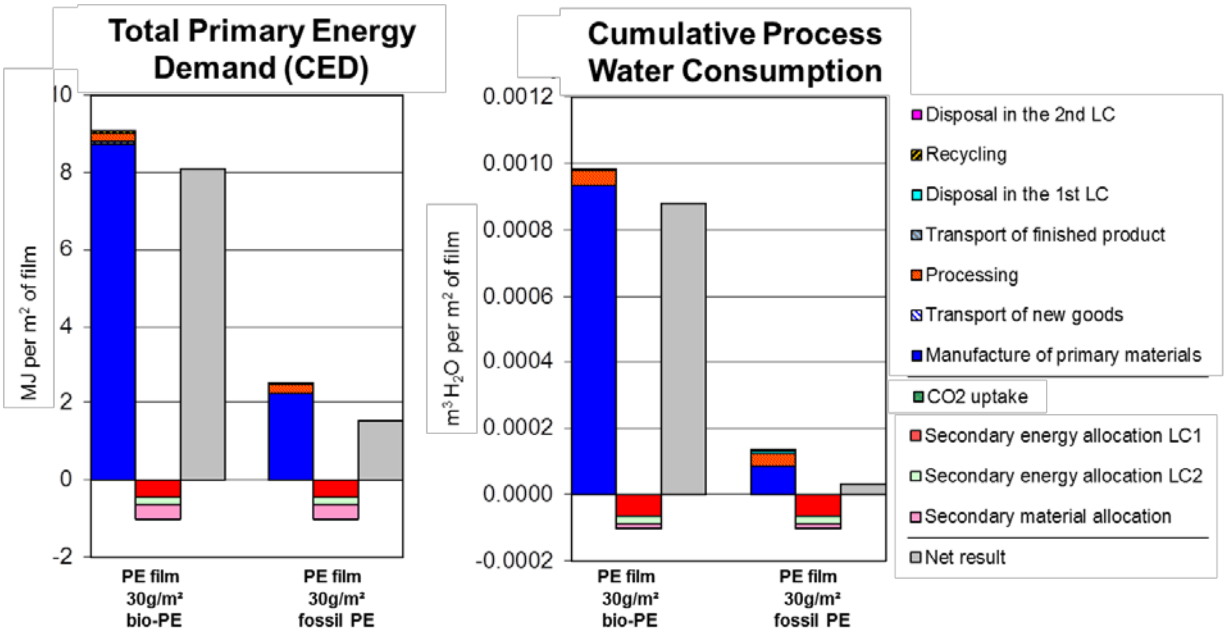

Figure 18: Comparative LCA of film packagings made of fossil PE and bio-PE (Results for the Total CED and Cumulative Process Water Consumption indicators)

The Land Use: Farmland indicator is shown based on space required. This information comes from the life cycle inventory. It was not possible to make an assessment of impact as part of this screening LCA.

Mentionable contributions to the Acidification Potential and Terrestrial and Aquatic Eutrophication impact categories for the PE system originate from sugar cane cultivation. The high contribution by the raw material production stage in the Human Toxicity impact category for the bio-PE system result from sugar cane conversion, especially from emissions during bagasse burning.

This finding is quite typical of product lines from agricultural biomass. It should also be pointed out that there is only little information regarding direct emissions from these process steps that relates to Brazilian local conditions. It is difficult to evaluate the validity of the data.

The analysis of the Total Cumulative Energy Demand (CED) life cycle inventory variable shows a clearly higher primary energy demand for the bio-PE system. The CED typically supplements the Consumption of Fossil Resources and Climate Change impact categories as a key indicator over the total energy demand of the product systems under review. In the case on hand, it is striking that the Total CED results are diametrically opposed to the results of the impact assessment for the Climate Change and Consumption of Fossil Resources indicators. An explanation can be found in the high percentage of regenerative primary energy that is used during the production of bio-PE.

Cumulative Process Water Consumption is also rather a life cycle inventory variable that does not contain an impact assessment. The bio-PE system has a clearly higher water consumption than the fossil-based product line. The diagram shows that the most contributions originate from raw material production, for bio-PE they go back to the data from sugar cane cultivation.

Concluding, we can summarize that the bio-PE system has advantages over the fossil-based product line in the Climate Change and Consumption of Fossil Resources impact categories, which are relevant for the public and political discussion with a global focus. But the disadvantages of the bio-PE system in the Acidification, Eutrophication, and Human Toxicity impact categories should not be withheld. The diagrams show that the disadvantages of the bio-PE system compared to the fossil PE system are evident when looking at the eutrophying emissions and the fine dust emissions. A final overall evaluation can only result from weighing different standpoints.

Based on the UBA method of evaluating the results of life cycle assessments, no overall ecological advantage or disadvantage can be derived for the bio-PE system[14].

4.2.4 Comparative LCA of 15g bowls with a hinged lid made of PLA and PS

The raw material for producing PLA is lactic acid, which is extracted from agricultural products. The initial product for PLA production today most frequently is maize; in principle, other crops such as sugar beets or crop residues like wheat or maize straw are suitable as well. The goal of this screening life cycle assessment is a comparison of bowls with a hinged lid made of PLA and polystyrene.

This screening LCA analyses sugar beets and lignocellulose from maize straw as biomass starter products for PLA production. Allocation is based on specifications of the RED Directive.

Two technological references are used for sugar production from lignocellulose and for lactic acid production. The former represents today's state of the art, the second is a forecast of future production techniques.

The weight of all bowls studied is set at 15 g, the functional unit for the LCA comparison are 1,000 hinged-lid bowls.

The screening life cycle assessment includes the following life cycle stages:

- Cultivation of the crops
- Transport of the biomass
- Processing of the biomass
- Lactic acid production
- Polymerization of lactic acid
- PS production
- Transport of the raw materials
- Manufacture of the hinged-lid bowls
- Recycling
- Disposal

[14] According to information received from the Brazilian bio-PE manufacturer Braskem, a life cycle assessment is being performed for bio-PE, and conformity with ISO 14044 will be ensured by involving a team of critical experts. This study will probably be completed in the first half of 2012. This would provide a uniform and valid database for the ecological assessment of bio-PE.

- Allocation of the use of secondary materials and secondary energy from recycling and disposal processes in the form of credits
- Accounting (credits) for the CO2 bound in the PLA

The following five scenarios were balanced for the LCA comparison:

A. 15g hinged-lid bowl made of PLA / sugar beet “today”

  - Packaging material: PLA from sugar beet
  - Lactic acid production: Status quo
  - Weight: 15 g
  - Collection rate: 80%
  - Recycling rate: 0%
  - Credit from recycling:
    - Polymer recycling: none
    - Mechanical recycling: Polyolefin credit (substitution factor 0.7)
    - Energy recovery: Substitution of hard coal in the cement works
    - Credit from disposal: Power and heating energy Germany

B. 15g hinged-lid bowl made of PLA / sugar beet “future”

   Identical assumptions like in the previous scenario A, but with a technically improved lactic acid production process (lactic acid production: future).

C. 15g hinged-lid bowl made of PLA / ligno-cellulose “today”

D. 15g hinged-lid bowl made of PLA / ligno-cellulose “future”

   The differences between scenarios C and A and D and B are the biomass used as raw material and the conversion into sugar. All other assumptions are identical.

E. 15g hinged-lid bowl made of PS

   The differences to scenarios A-D are:

  - Packaging material: PS
  - Recycling rate: 64% of the packagings collected for recycling (like in the Danone yogurt pot study [Kauertz et al. 2011])
  - Credit from recycling:
    - Polymer recycling: PS credit (substitution factor 0.98)
    - Mechanical recycling: PO credit (substitution factor 0.7)
    - Energy recovery: Substitution of hard coal in the cement works

Results:

The results can be seen in Figures 19 to 28. The comparative study of hinged-lid bowls made of PLA and PS shows:

- a smaller environmental burden from hinged-lid bowls made of PLA based on the indicators:
  - Climate Change
  - Consumption of Fossil Resources and
  - Summer Smog (POCP)
  - *Acidification Potential ("future" lignocellulose scenario only)*
  - *Human Toxicity: Fine Dust (PM10) (future scenarios only)*
- a higher environmental burden from hinged-lid bowls made of PLA based on the indicators:
  - *Acidification Potential (compared to the "future" lignocellulose scenario only)*
  - Terrestrial Eutrophication
  - Aquatic Eutrophication
  - *Human Toxicity: Fine Dust (PM10) (compared to status-quo scenarios only)*

The following statements are valid:

- The results from all indicators analysed are determined by the loads of raw material production for both the PLA systems and the PS systems.
- The load distribution of raw material production for the PLA systems shows that lactic acid production is the determining life cycle stage in the PLA production. For most indicators analysed, the loads associated with lactic acid make up the greatest single contribution to the overall system loads.
- The contributions from the PS production cannot be further broken down due to the data available (aggregated record).
- The results for hinged-lid bowls made of PLA from lignocellulose do not carry any loads in the cultivation and biomass transport life cycle stages because lignocellulose is considered a crop residue in line with the RED Directive and therefore is not assigned loads from cultivation.
- The PLA systems receive fewer credits than the PS system (exception: Climate Change indicator) because no material credits for regranulate from the polymer sort-specific fraction are taken into account, since there is currently no PLA recycling in Germany. The material credits documented originate from the PO credit for the regranulate from the mechanical recycling of the mixed plastics fractions. There are also fewer energy credits for the PLA system because the calorific value of PLA is lower than that of PS.
- The PLA system gets a credit in the Climate Change indicator for the CO2 bound in the material that the plants have absorbed during their growth phase.
- In the Climate Change indicator, CO2 emissions from the disposal of the packaging system visibly contribute to the LCA result of the packagings studied.

- Most of the above-average contributions from the lactic acid production life cycle stage in the Acidification Potential impact category originate from the upstream sulphuric acid chain based on an EcoInvent module which the authors of this report could not validate any further.

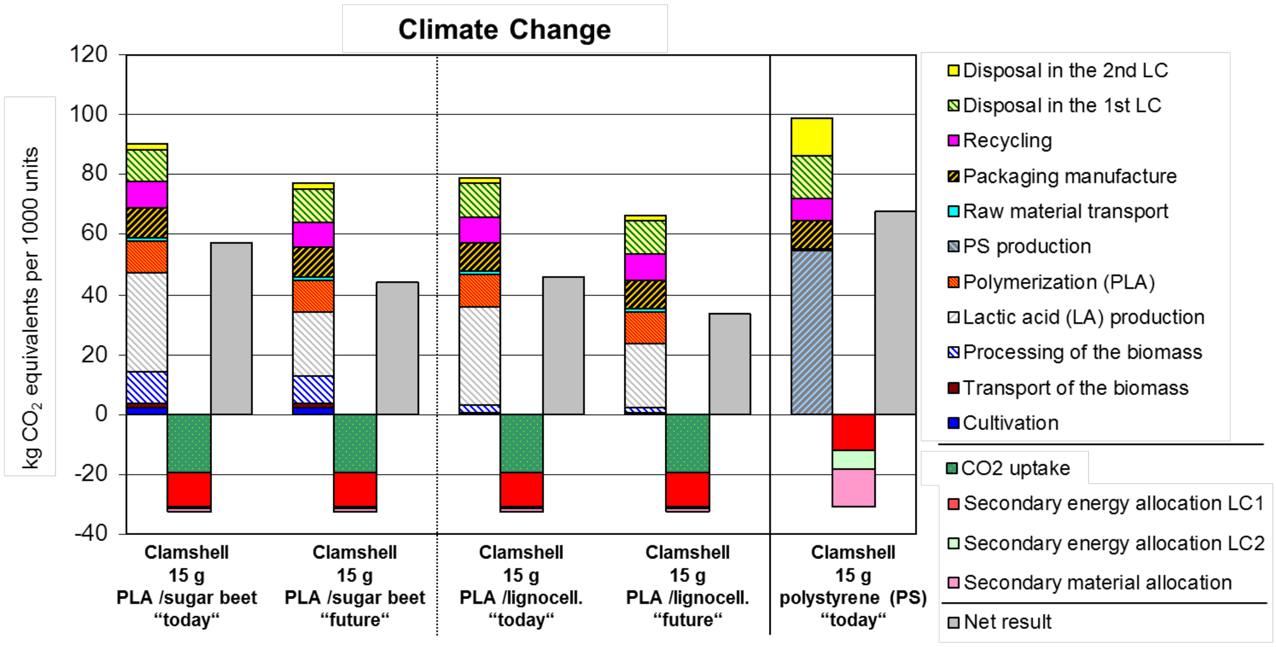

Figure 19: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Climate Change indicator)

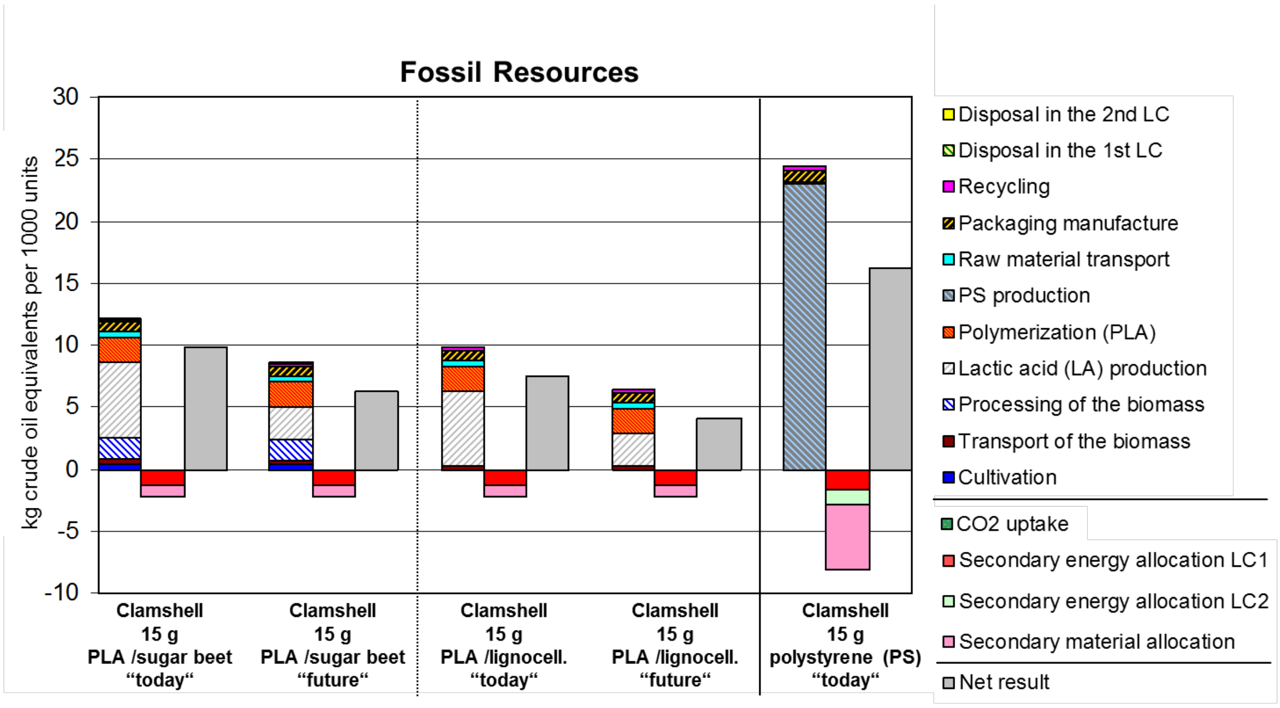

Figure 20: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Consumption of Fossil Resources indicator)

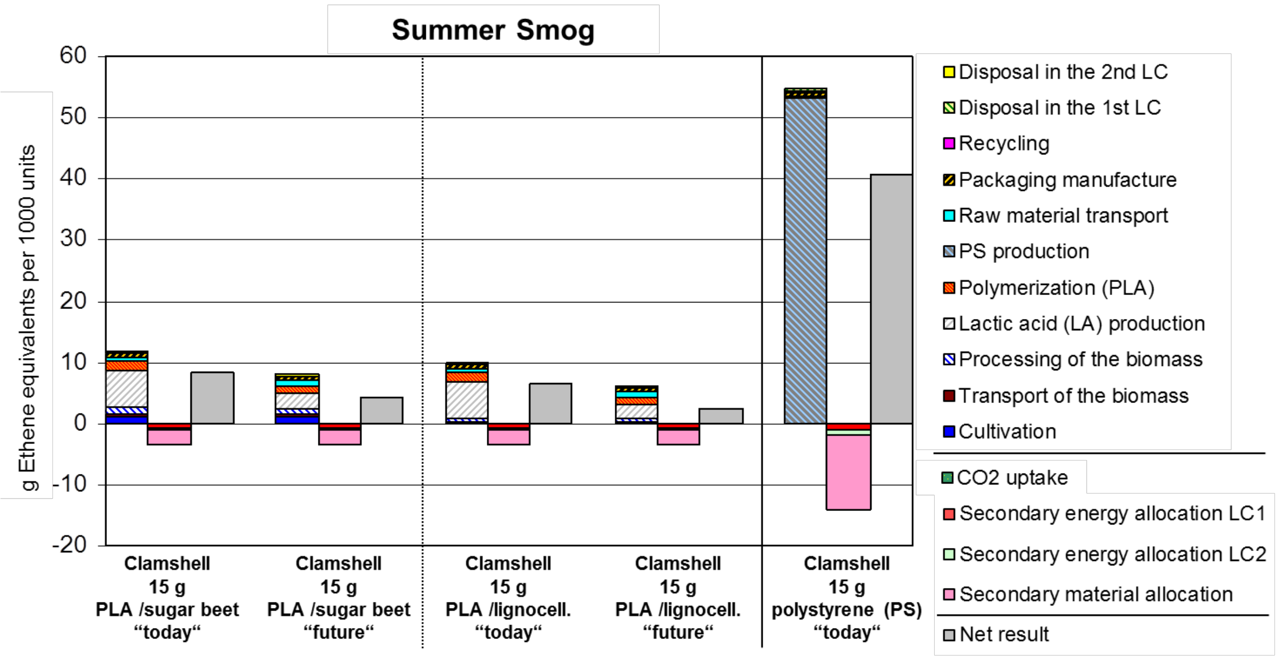

Figure 21: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Summer Smog POCP indicator)

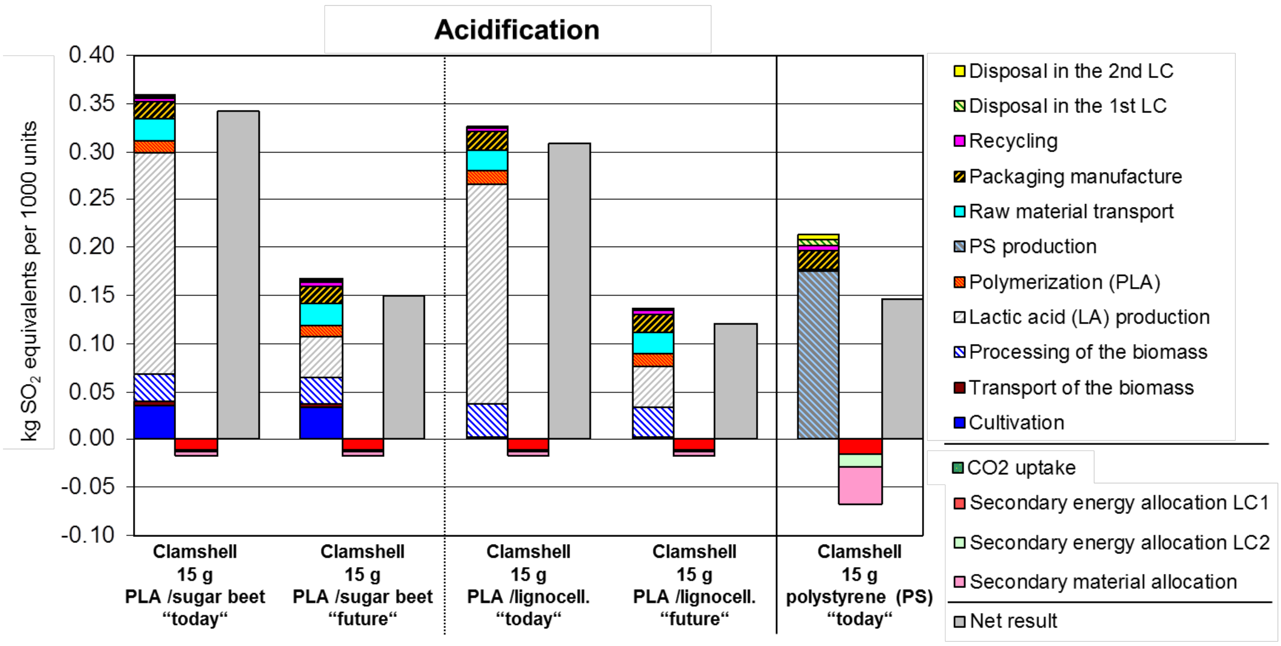

Figure 22: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Acidification indicator)

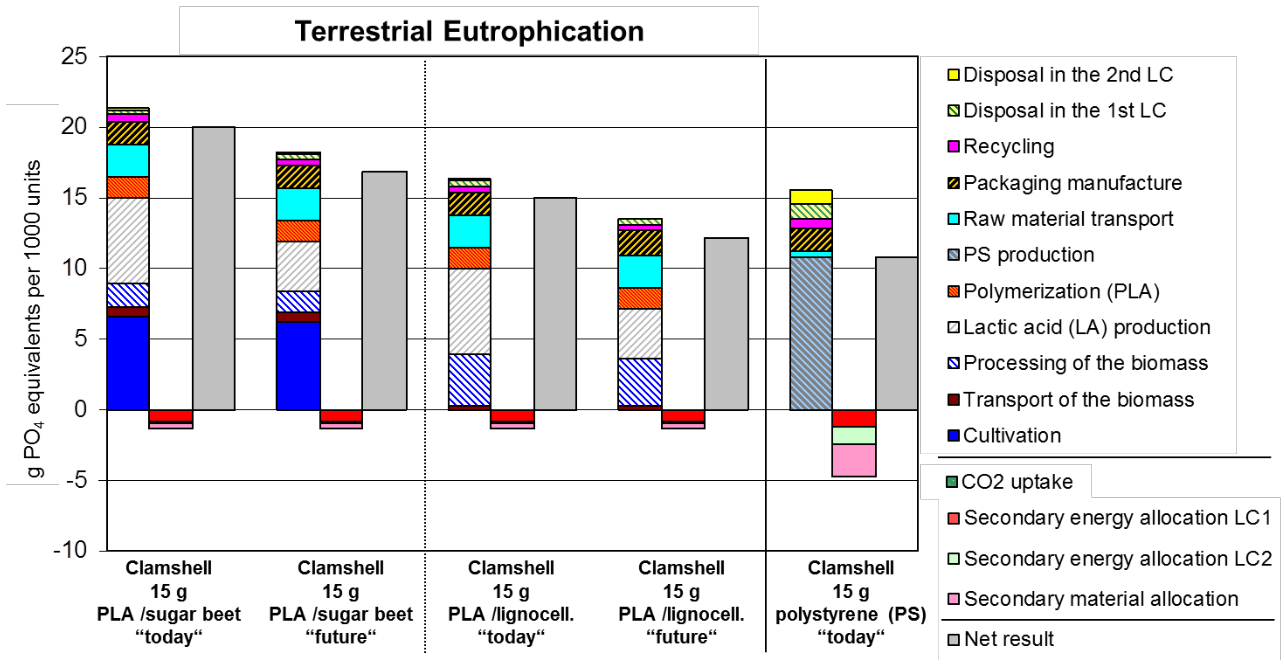

Figure 23: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Terrestrial Eutrophication indicator)

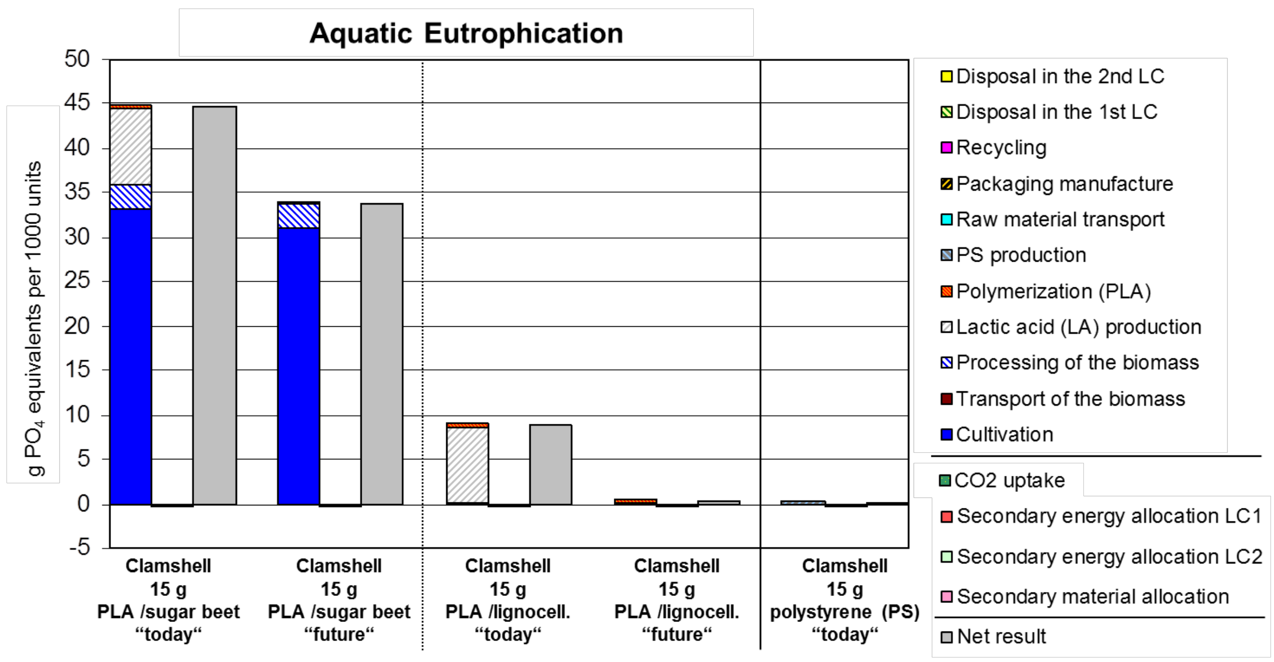

Figure 24: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Aquatic Eutrophication indicator)

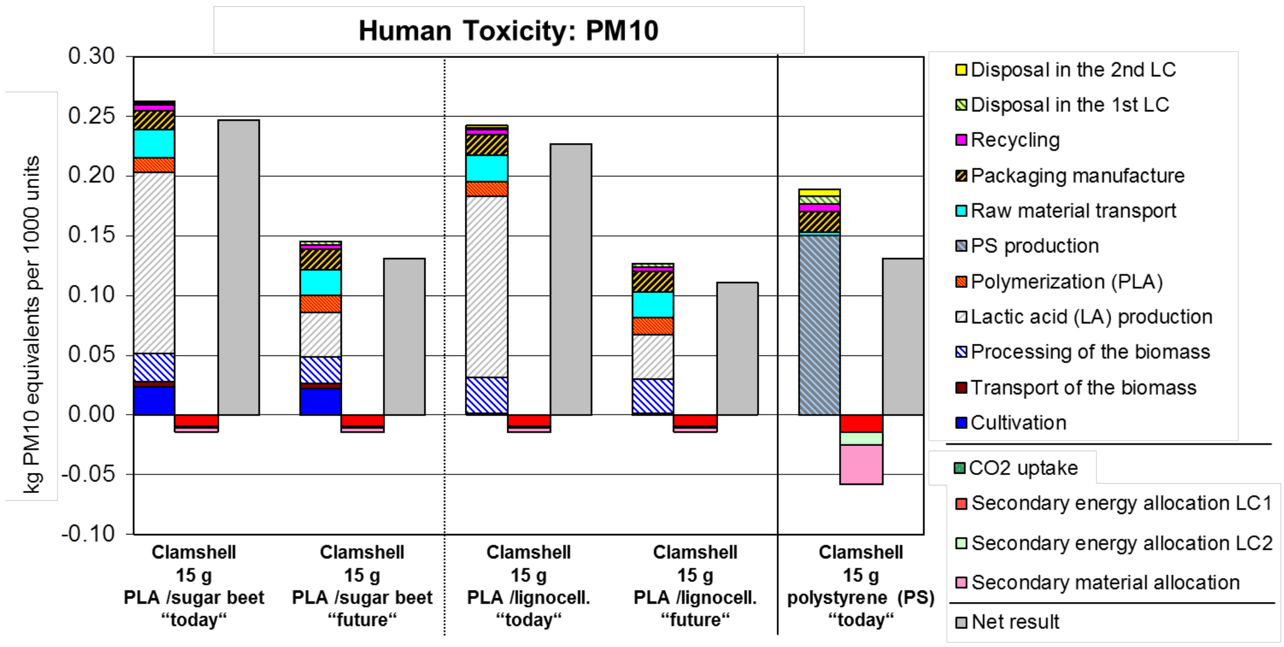

Figure 25: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Human Toxicity: PM10 indicator)

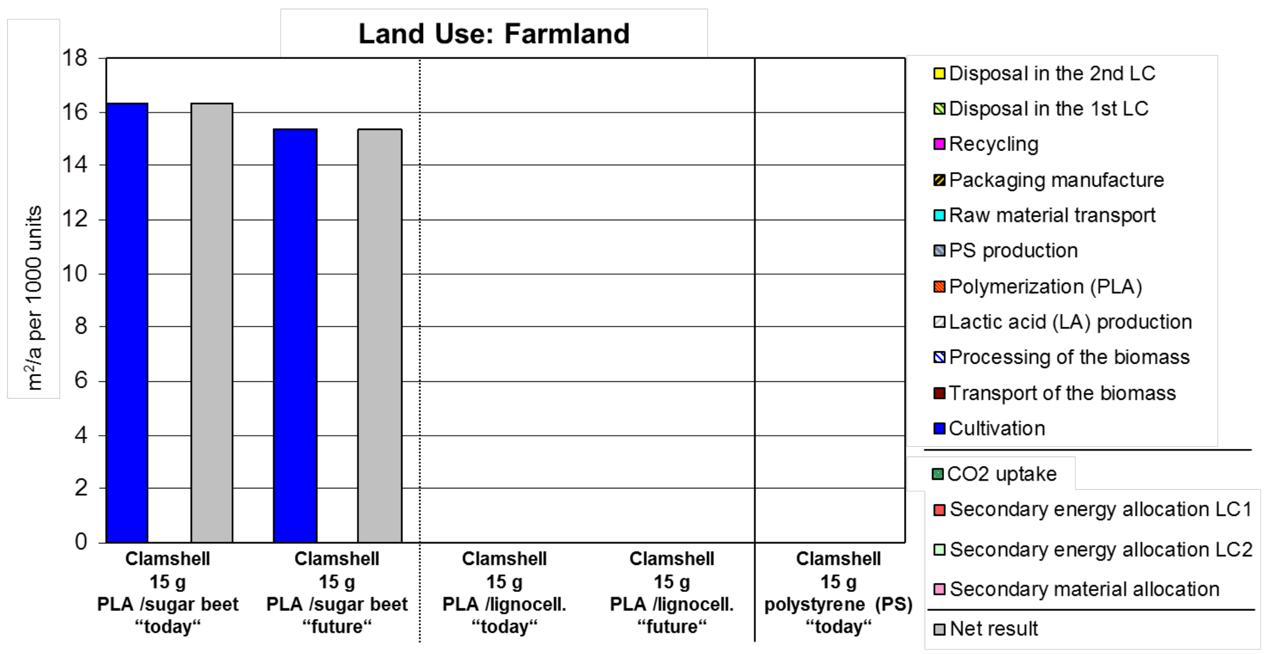

Figure 26: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Land Use: Farmland indicator)

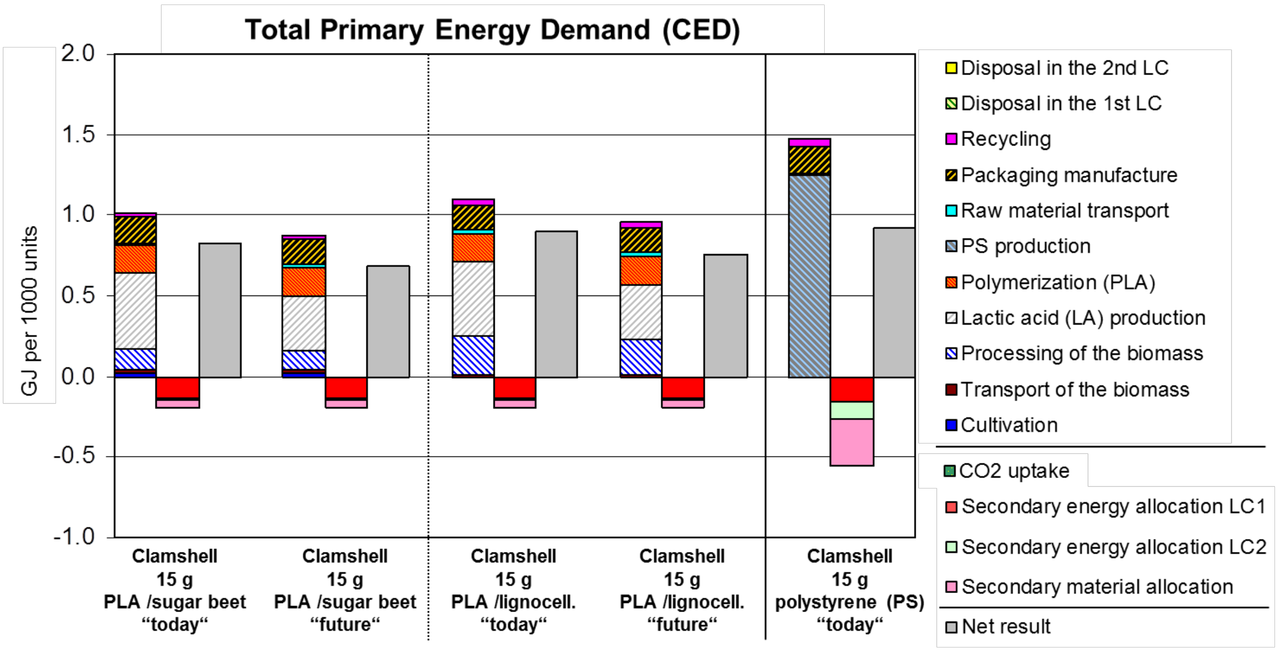

Figure 27: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Total Primary Energy Demand (CED) indicator)

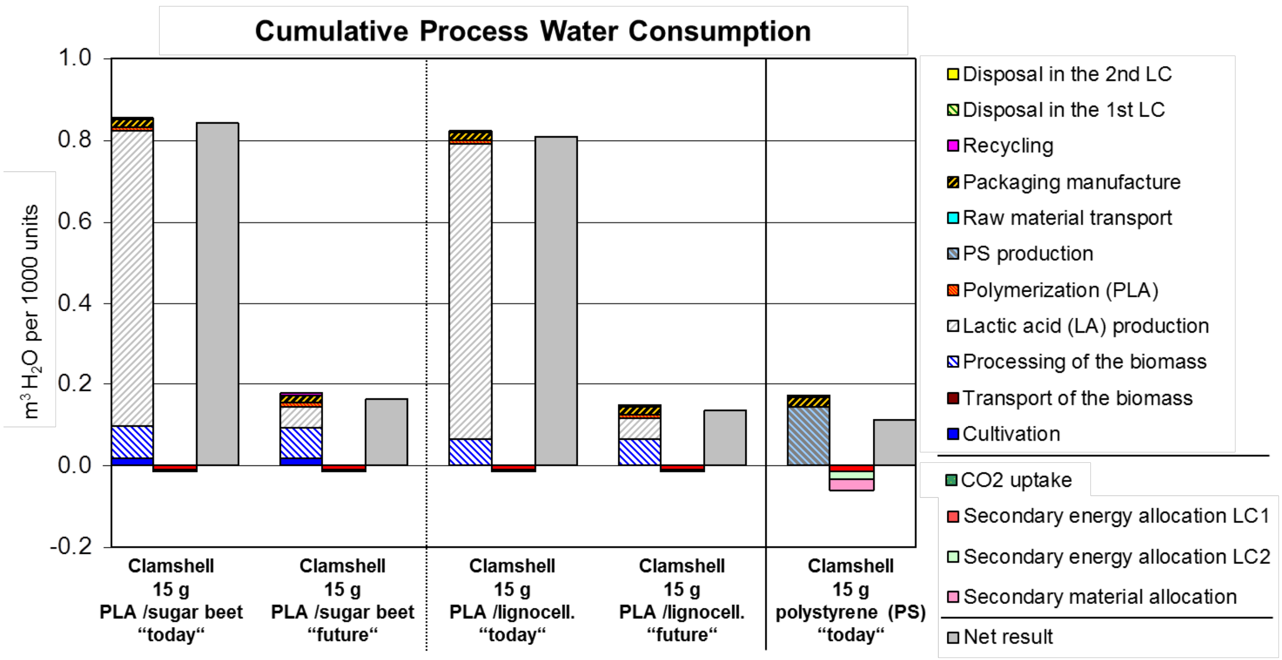

Figure 28: Comparative LCA of hinged-lid bowls made of PLA and PS (Results for the Cumulative Water Consumption indicator)

The Land Use: Farmland indicator is shown based on space required. This information comes from the life cycle inventory. It was not possible to make an assessment of impact as part of these screening LCAs.

The life cycle stage of biomass cultivation shows comparatively high contributions in the Terrestrial and Aquatic Eutrophication impact categories, which is due to field emissions, like in the case of bio-PE. These do not occur in the PLA from lignocellulose scenarios because of the allocation according to the RED Directive. Therefore, these scenarios show clearly reduced contributions to the Terrestrial and Aquatic Eutrophication impact categories.

The future estimate for lactic acid production shows a visible improvement of this process step. The reduction of emissions is caused by a reduction of the energy and process materials demand and an improvement of the process yield, which also becomes apparent in reduced loads in upstream life cycle stages. Lactic acid production is the driving life cycle stage for the life cycle inventory variable of Cumulative Process Water Consumption.

A final assessment of the findings shown here is difficult without standardization and further ordering of the impact categories under review; these optional elements of the LCA have to be omitted for cost considerations.

The results show a similar picture like the screening LCA for films: advantages for the bio-based product lines in the Climate Change, Consumption of Fossil Resources, and Summer Smog (POCP) impact categories, and disadvantages in the Acidification, Eutrophication, and Human Toxicity impact categories.

The PLA systems that are produced based on crop residues (PLA from lignocellulose) show advantages over products made of PLA from sugar beets, since 100% of the loads from cultivation are allocated to the grains according to RED specifications, which means that the straw enters the calculations without a CO2 backpack or charges of field emissions. In this respect, hinged-lid bowls made of PLA from lignocellulose achieve better results than the hinged-lid bowls made of PLA from sugar beets and pose less disadvantages compared to bowls made of PS in the impact categories that are mainly influences by field emissions.

It should also be noted for the discussion that the future improvements may significantly reduce the existing differences.

Based on the UBA method of evaluating the results of life cycle assessments, no overall ecological advantage or disadvantage can be derived for the hinged-lid bowls made of PLA under the framework parameters of the status quo scenarios.

The situation for the future scenarios is such that the LCA comparison of hinged-lid bowls made of PLA/lignocellulose vs. hinged-lid bowls made of PS results in an overall ecological advantage of hinged-lid bowls made of PLA/lignocellulose. The results of the LCA comparison of the future scenarios of hinged-lid bowls made of PLA/sugar beet vs. hinged-lid bowls made of PS do show an overall ecological advantage of the hinged-lid bowls made of PLA/sugar beet. But this result should be verified in the future using real-life process data.

4.3 Analysis of the studies

4.3.1 Overview of the literature reviews analysed in depth

The studies are listed below with a short description; they were assigned to groups based on their object of study.

The first three groups A to C (see below) are packaging applications that currently represent the most important bioplastic packagings according to the market analysis. Most of the life cycle assessment studies analysed here consider the complete life cycle including packaging production and use as well as disposal. They provided the foundation for assessing the current ecological status of bioplastic packagings. In addition, two screening LCA studies were analysed in group D that were included in a supplementary capacity.

There was only one published LCA study for the new bioplastics that are of the same material as the conventional plastics (for bio-PE, group E). The analysis of this study is supplemented by the findings of the screening LCA described in Section 4.2.3.

Group F includes a study on packagings made of Mater-Bi, which is the most important bioplastic of European production in terms of quantity. It is the only more recent life-cycle assessment we found for Mater-Bi. It covers the use of the material as cutlery. It therefore does not fit directly into groups A-C. But the study takes an approach used to study potential advantages of biodegradable bioplastics in bio-waste management. It is interesting for our research project under this aspect as well.

In group G, we analyse studies that deal with PLA. Unfortunately, these studies include the packaging sector or the currently relevant methods to a limited extent only. Since there are no better studies available, these were included because this group of packagings could gain significance in the packaging sector.

Packaging application groups or polymer types

A. **(Flexible) film products**

- [Wellenreuther et al. 2009a]

  Title: Life Cycle Assessment of Waste Bags

  Object of study: Waste bags made of polyethylene (PE-HD, LPE-LD) and bioplastics

  Bioplastic materials: Biopar (starch + 49% PBAT), Ecovio (PLA + 68% PBAT)

  Reason for selection: compliant with ISO 14044, transparent documentation, complete life cycle, comprehensive selection of impact categories; representative example of the packaging application group; reflection of German local conditions

- [Murphy et al. 2008]

  Title: Life Cycle Assessment (LCA) of Biopolymers for single-use Carrier Bags

  Object of study: Carrier bags made of PE-HD and bioplastics

  Bioplastic materials: Bag made of Mater-Bi® (50%starch, 50% polycaprolactone)

  Octopus bag prototype made of polylactic acid (PLA) and Ecofoil (fossil-based biodegradable bioplastic)

  Reason for selection: compliant with ISO 14044, complete life cycle, comprehensive selection of impact categories; representative example of the packaging application group

  Restrictions: comparative analysis of single indicator results; geographic reference is the UK, uses some very old plastic inventories

- [Chaffee et al. 2007]

  Title: Life Cycle Assessment for Three Types of Grocery Bags

  Object of study: Carrier bags made of PE-HD and bioplastics

  Bioplastic materials: Blend of 65% EcoFlex®(fossil-based biodegradable bioplastic), 10% polylactic acid (PLA), and 25% calcium carbonate

  Reason for selection: complete life cycle, based on ISO incl. critical review, selection of impact categories not limited to fossil resources and climate change; representative example of the packaging application group

  Restrictions: Geographic reference to the United States

- [Garrain et al. 2007]

  Title: LCA of biodegradable multilayer film from biopolymers

  Object of study: Biodegradable multi-layer films for packaging foods

  Bioplastic materials: PLA and starch blend (copolymer PCL)

  Reason for selection: complete life cycle, selection of impact categories not limited to fossil resources and climate change; representative example of the packaging application group

  Restrictions: Geographic reference unspecified, uses some very old plastic inventories

- [Hermann 2010]

  Title: Twisting biomaterials around your little finger: environmental impacts of bio-based wrappings

  Object of study: Comparison of laminated packaging films made of bio-based materials with films made of conventional plastics. A total of 32 alternatives was studied, of which 17 were inner packagings, 15 were outer packagings.

  Bioplastic materials:

  Inner packagings

  - Polylactic acid laminates (PLA)
  - Paper laminates

  (Conventional inner packaging made of: OPP, polyethylene (PE), and metallized OPP (MOPP)).

  The following laminates were studied as outer packagings:

  - PLA
  - Metallized PLA (MPLA)
  - Bio-based polyethylene
  - Paper laminates, e.g. with bio-based polyester (BBP) or ethylvinyl acetate (EVA)
  - Cellulose films

  (Conventional laminates from OPP and PE)

  Reason for selection: complete life cycle; representative example of the packaging application group

Restrictions: Impact assessment of the complete life cycle only based on climate change and energy; wider selection of environmental indicators only referring to “cradle to gate”, i.e. to the finished film, without packaging application and disposal.

B. Shape-retaining products made of PLA (pots, hinged bowls)

- [Kauertz et al. 2011] Pots

  Title: LCA Activia-Becher

  Object of study: Yogurt pots made of PS and PLA

  Bioplastic materials: PLA

  Reason for selection: compliant with ISO 14044, complete life cycle, comprehensive selection of impact categories; representative example of the packaging application group

- [Binder and Woods 2009] Cups

  Title: Comparative Life Cycle Assessment of Drinking Cups

  Object of study: One-way cups made of PP, PET, and PLA

  Bioplastic materials: PLA

  Reason for selection: LCA compliant with ISO 14044, complete life cycle, comprehensive selection of impact categories; representative example of the packaging application group

- [Pladerer et al. 2008] Cups

  Title: Vergleichende Ökobilanz verschiedener Bechersysteme beim Getränkeausschank an Veranstaltungen [Comparative life cycle assessment of various cup systems for beverage service at events]

  Object of study: One-way cups made of PS, PET, and PLA[15]

  Bioplastic materials: PLA

  Reason for selection: LCA partially includes German local conditions, based on ISO 14044, complete life cycle, comprehensive selection of impact categories; representative example of the packaging application group

- [Ovam 2006] Cups

  Title: Comparative LCA of 4 types of drinking cups used at events

  Object of study: Cups for cold beverages made of PP and PLA (one-way) and polycarbonate (multi-way)

[15] In addition, one-way cups made of coated cardboard, one-way cups made of recycled material, and multi-way cups made of PP. These are not studied in depth in our research project.

Bioplastic materials: PLA

Reason for selection: compliant with ISO 14044, complete life cycle, comprehensive selection of impact categories; representative example of the packaging application group

Restrictions: comparative analysis of single indicator results; geographic reference is Belgium, missing proof that data sources are representative

- [Bohlmann 2004] Pots

Title: Biodegredable Packaging Life Cycle Assessment

Object of study: Yogurt pots made of PP and PLA

Bioplastic materials: PLA

Reason for selection: based on ISO 14044 without critical review, complete life cycle, representative example of the packaging application group; studies the influence of process optimization in PLA production

Restrictions: Restricted to climate change and CED; geographic reference United States

- [Detzel and Krüger 2006] Hinged bowls

Title: Life Cycle Assessment of Polylactide (PLA) - A comparison of food packaging made from NatureWorks® PLA and alternative materials

Object of study: Hinged bowls made of PET, PS, PP, and PLA

Bioplastic materials: PLA

Reason for selection: compliant with ISO 14044, transparent documentation, complete life cycle, comprehensive selection of impact categories; representative example of the packaging application group; reflection of German local conditions

- [Madival et al. 2009] Hinged bowls

Title: Assessment of the environmental profile of PLA, PET and PS Klappschale containers using LCA methodology

Object of study: Hinged bowls made of PET, PS, and PLA

Bioplastic materials: PLA

Reason for selection: based on ISO 14044 without critical review, complete life cycle, representative example of the packaging application group

Restrictions: insufficient proof that data sources are representative; geographic reference to the United States; focused on studying the influence of transport distances

- [Groot and Boren 2010] PLA polymers

Title: Life cycle assessment of the manufacture of lactide and PLA biopolymers from sugarcane in Thailand

Object of study: Lactides and PLA compared to various conventional synthetic polymers (PET, PE, PP, PS, PA6, PC, PMMA, PVC, EPS, ABS)

Bioplastic materials: Lactides and PLA from Thai cane sugar

Reason for selection: comprehensive selection of impact categories; sugar cane viewed as a raw material source for PLA

Restrictions: life cycle under review ends after the PLA production stage

C. Loose-fill

- [Würdinger et al. 2002]

Title: Kunststoffe aus nachwachsenden Rohstoffen – vergleichende Ökobilanz für Loose-Fill-Packmittel aus Stärke bzw. aus Polystyrol [Plastics made of renewable raw materials – a comparative life cycle analysis of loose-fill packagings made of starch or polystyrene]

Object of study: Comparison of loose-fill material made of starch and fossil PS

Bioplastic materials: Foamed starch from potatoes, wheat, and maize

Reason for selection: LCA compliant with ISO 14044, transparent documentation, complete life cycle, comprehensive selection of impact categories; representative example of the packaging application group; reflection of German local conditions

D. Various bio-based products and polymers

- [Shen and Patel 2008]

Title: Life Cycle Assessment of Polysaccharides: A Review

Object of study: Review of various studies in which starch-based products were rated from an ecological point of view

Bioplastic materials: among others: Loose-fill

Reason for selection: Patel is a much quoted author in the context of environmental evaluation of starch-based products.

Restrictions: no LCA, just a literature review

- [Patel et al. 2003a]

Title: Environmental assessment of bio-based polymers and natural fibres

Object of study: Review of various studies in which various bioplastics were rated from an ecological point of view

Bioplastic materials: Starch-based products, PHA and PLA

Reason for selection: Patel is a much quoted author in the context of environmental evaluation of starch-based products.

Restrictions: no LCA, just a literature review

E. Bio-polyethylene (polymer)

- [Liptow and Tillman 2009]

  Title: Comparative life cycle assessment of polyethylene based on sugarcane and crude oil

  Object of study: Comparison of bio-PE and fossil PE

  Bioplastic materials: Bio-PE made of Brazilian sugar cane

  Reason for selection: Selection of impact categories not limited to fossil resources and climate change; bio-PE viewed as current innovation in the field of bioplastics

  Restrictions: Emissions into the soil and water during the production of bio-ethanol were not taken into account; fossil PE with geographic reference to Sweden; life cycle: without packaging use, waste disposal (of the PE granulates), simplified treatment as a combustion process

F. Shape-retaining products made of Mater-Bi

- [Razza et al. 2008]

  Title: Compostable cutlery and waste management: An LCA approach

  Object of study: Cutlery made of PS and Mater-Bi including disposal of food residues

  Bioplastic materials: Mater-Bi YI

  Reason for the selection: complete life cycle; impact categories not limited to fossil resources and climate change; example of packaging product made of Mater-Bi as an important bioplastic material, compliant with ISO 14044; gives indications on steering options under a bio-waste treatment strategy when biodegradable materials are used as packaging materials

  Restrictions: Sources of records used are referenced but records are not characterized as representative in the study itself; the results do not allow a direct comparison of PS and Mater-Bi because waste treatment of the food residues is always included.

G. PHA (various applications)

- [Pietrini et al. 2007]

  Title: Comparative Life Cycle Studies on Poly(3-hydroxybutyrate)-Based Composites as Potential Replacement for Conventional Petrochemical Plastics

  Object of study: Comparison of conventional synthetic polymers

  Bioplastic materials: Polyhydroxybutyrate (PHB) composites

  Reason for selection: there are hardly any LCAs on PHA; variants of the biomass are analysed: PHA made from cane sugar and maize starch

  Restrictions: Impact assessment limited to fossil resources and climate change; no packaging application; views moulded parts for monitors and cars

- [Kurdikar et al. 2002]

Title: Greenhouse Gas Profile of a Plastic Material Derived from a Genetically Modified Plant

Object of study: Comparison of PHA with fossil PE

Bioplastic materials: PHA directly produced in maize plants

Reason for selection: there are hardly any LCAs on PHA; variants of the biomass are analysed: PHA made from cane sugar and maize starch

Restrictions: Impact assessment limited to climate change; life cycle ends at polymer production stage; U.S. geography

Note:

The PLA eco-balanced in the studies mentioned above was typically balanced with the inventory data provided by NatureWorks. This information is based on the production process of NatureWorks and their PLA product, Ingeo, which is currently produced exclusively in the U.S. and from U.S. maize. These PLA inventories cannot simply be transferred to other PLA manufacturers.

[Groot und Boren 2010] and the screening LCAs performed by IFEU modelled the PLA production using other data sources, because these also considered specific biomass raw materials.

4.3.2 General influencing factors

The LCA studies of application groups A-C show that specific aspects significantly determine the results of the comparison. These include, in particular:

- Age and representativity of the eco-inventory (input-output record) of polymer or material production
- Assumed weight of the bioplastic packaging compared to the conventional plastic packaging
- Percentage of biomass in the finished material
- Consideration of impact categories that are highly determined by the agricultural supply of biomass and by the energy supply for biomass conversion
- Assumptions regarding disposal routes

Supplementary notes on the first two items can be found below.

1. Eco-inventories

An extensive database of eco-inventories on conventional plastics is made available by the European plastics industry (www.plasticseurope.com). The situation for bioplastics is much more difficult. The only eco-inventories that are accessible to the public are for the PLA (Ingeo) produced by NatureWorks only; download at www.natureworksllc.com.

Furthermore, eco-inventories for maize starch and potato starch can be found in databases accessible to the public. LCA studies ultimately depend on supplementing this data with other process data. The quality of the data is highly dependent on the processing depth of an LCA and on the willingness of biopolymer manufacturers to provide (mostly confidential) information.

In addition, the data will change over time due to process optimization and innovation. Figure 29 shows a comparison of older and more recent PLA (Ingeo) and PET data, from which the above becomes apparent.

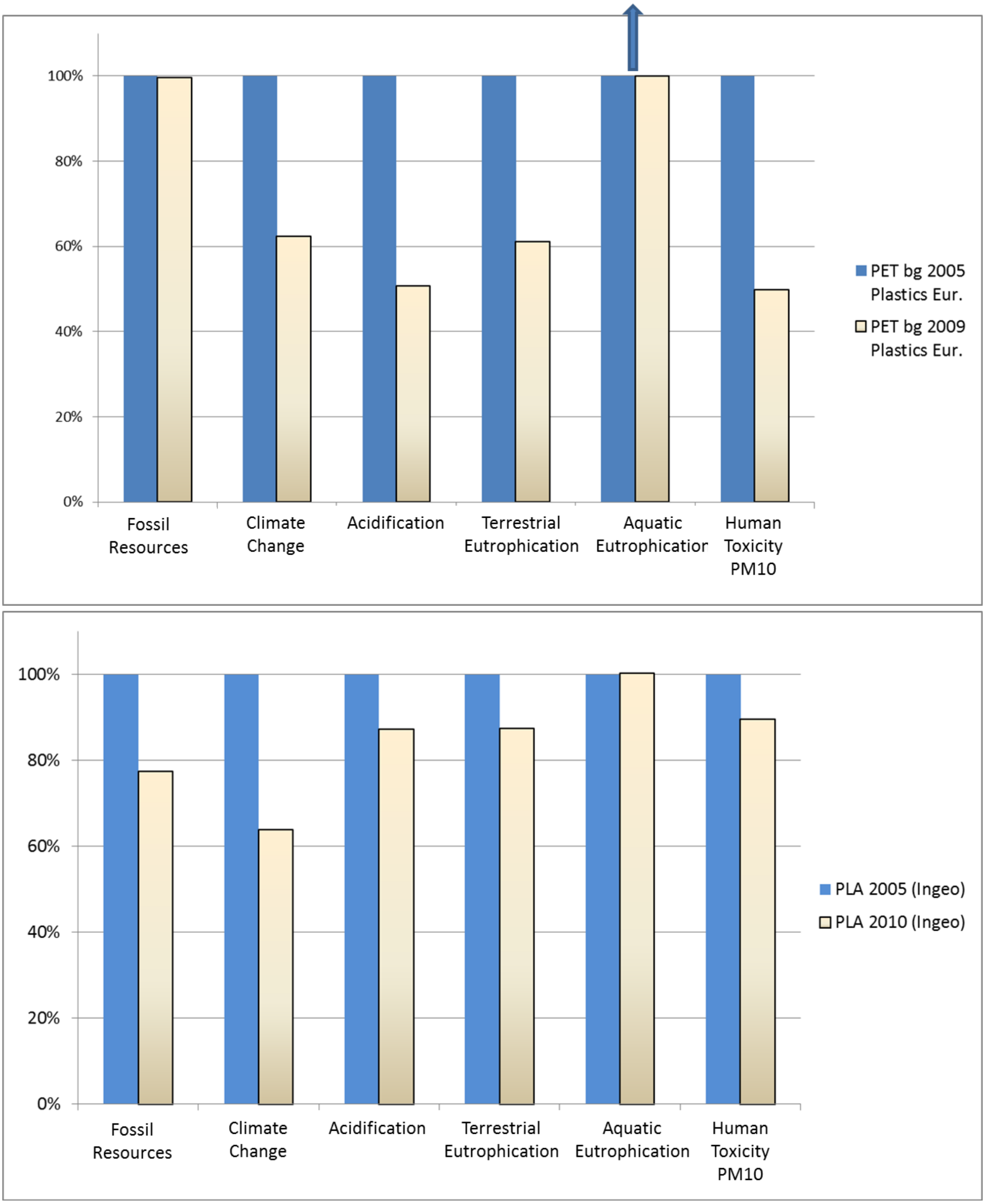

Figure 29: Relative changes of the environmental impact profiles of PET and PLA

Bg: PET suitable for bottles; upward arrow: Aquatic Eutrophication for PET bg 2009 is greater than for PET bg 2005

Source: Edited by IFEU based on [Plastics Europe 2010], [Vink 2010]

Both records have improved for most impact categories but the PET record for Aquatic Eutrophication has deteriorated. The changes of the PET data cannot be determined based on the information available. An innovation of the fermentation process implemented by NatureWorks explains the changes of the PLA data. The new process uses much less energy. Since the U.S. mains power consumed in the NatureWorks plant is heavily based on coal, the reduced energy consumption results in clearly reduced environmental loads in the Fossil Resources and Climate Change impact categories. The greatest contributions to Acidification and Terrestrial Eutrophication are made by field cultivation and maize mill, which is why the relative improvement is smaller here.

More comparisons of older and more recent records were derived from the result diagrams in [Wellenreuther et al. 2009a] (Figure 30). It is apparent that the Ecoflex production with NG technology (NG: next generation) results in clear improvements. Ecovio, which is produced from PLA and Ecoflex, shows much improved results if one compares a combination of the respective older records with a combination of records based on the respective innovative production methods.

The bioplastic Biopar also contains Ecoflex and benefits from the process innovation mentioned.

Supplementary information on the data in Figure 30:

<u>Ecoflex</u>: Data revision status of 2007

<u>Ecoflex NG (Next Generation):</u> Planning data, approximately relating to production in 2010/11

<u>Ecovio A:</u> Ecoflex + PLA 2005 databases

<u>Ecovio B:</u> Ecoflex NG + PLA 2010 databases

<u>Biopar A:</u> Ecoflex + starch databases

<u>Ecovio B:</u> Ecoflex NG + starch databases

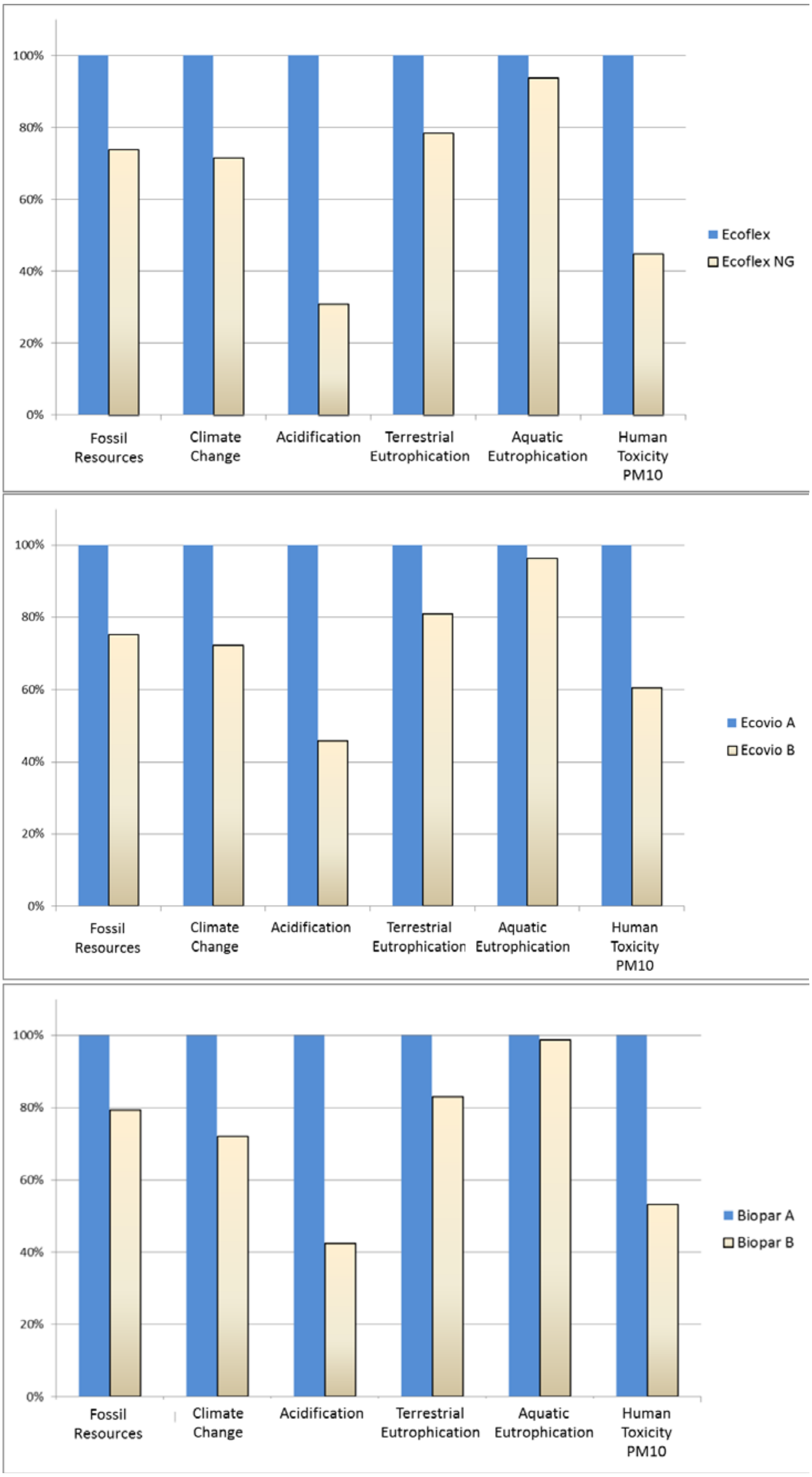

Figure 30: Relative changes of the environmental impact profiles of Ecoflex, Ecovio, and Biopar

Source: Edited by IFEU based on the result diagrams in [Wellenreuther et al. 2009a]

We mentioned that the bioplastics industry has hardly provided any eco-inventories yet. Innovia's home page at least provides a comparison of environmental impact profiles as a function of time (Figure 31).

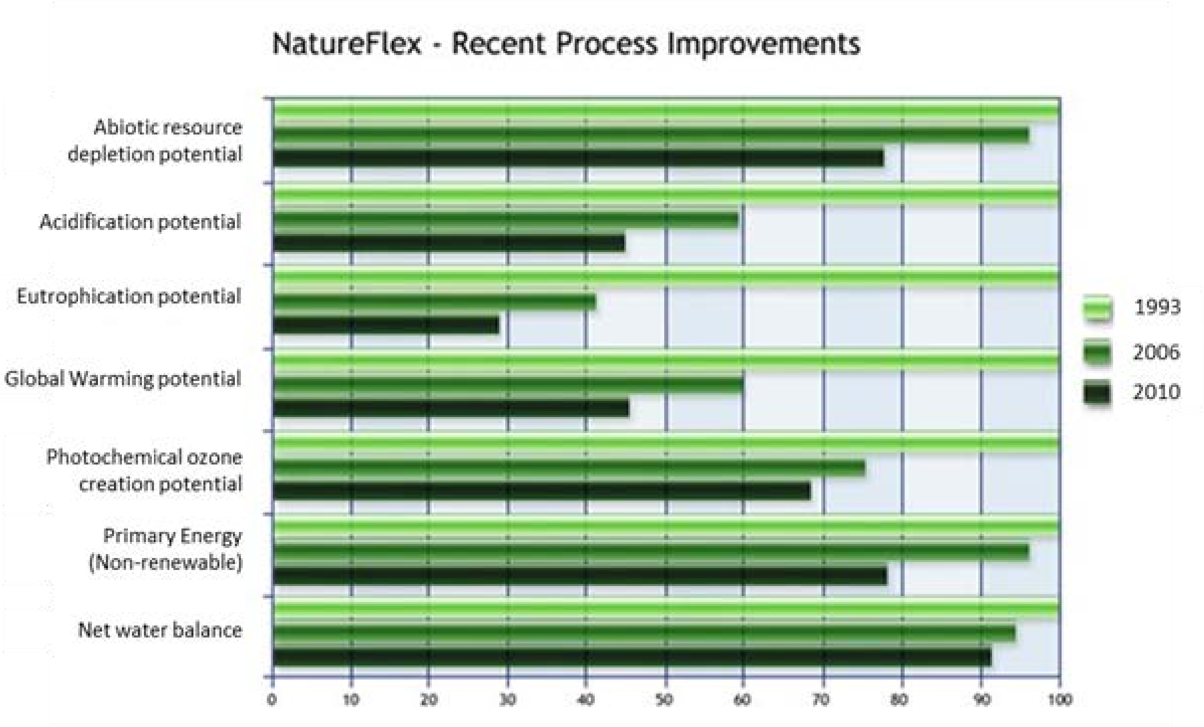

Figure 31: Relative changes of the environmental impact profiles of NatureFlex

Source: Diagram downloaded from www.innoviafilms.com/Environmental/Lifecycle-Assessment.aspx

This diagram also shows a reduction of potential environmental effects, which has primarily taken place in the period from 1993 to 2006. Many other changes in the general infrastructure (European standards for lorries, reduction of emissions from large combustion plants for power generation) were implemented in this period. The influence of direct process innovations on the overall improvement cannot be determined because additional required information is not available. Unfortunately, the LCA by Innovia on which this information is based is also not available to the public.

2. Weights of bioplastic packagings

Some studies assume greater weights for bioplastic packagings than for conventional plastic packagings. Examples:

- Loose-fill [Würdinger et al. 2002]
  - EPS: 4 kg / m3
  - Recycled material: 4 kg / m3
  - Starch: 12 kg / m3
- Waste bags: Film thicknesses and weights [Wellenreuther et al. 2009a]
  - PE-HD: 12,5 µ film thickness; 6.5-6.9 g/bag

- PE-LD: 20 µ film thickness; 10 g/bag
- Bioplastic (Biopar): 25 µ film thickness; 17.7 g/bag

(comparable bag sizes)

- Shopping bags: Weights [Chaffee et al. 2007]
    - PE-HD: 5.78 g/bag
    - Bioplastic (Ecoflex/PLA/$CaCO_3$) 15.78 g/bag

    (comparable bag sizes)
- Cups/pots: Weights [Bohlmann 2004]
    - PP: 7.9 g/pot
    - PLA: 8.91 g/pot

    (volume 8 oz.)
- Cups/pots: Weights [Pladerer et al. 2008]
    - PP: 12.73 and 13.18 g/cup
    - PLA: 13.6 and 14.4 g/cup

    (volume 16 oz.)
- Hinged bowls: Weights and density [Madival et al. 2009]
    - PET: 31.6 g/bowl (density 1370 kg/m³)
    - PS: 24.6 g/bowl (density 1052 kg/m³)
    - PLA: 29.6 g/bowl (density 1246 kg/m³)

    (Fill quantity 454 g)
- Composite films for food packaging [Garrain et al. 2007]

    Thicknesses but no weight information
    - PP-PA6-PP: 130-20-130 µ
    - Bioplastic: PLA-modified starch/PCL-PP: 25-200-25 µm

    (Due to the higher density of PLA and starch versus PP, the bioplastic in this example should have a 20% greater weight per unit area than conventional composite film)
- Shopping bags: Weights [James and Grant 2005] quoted in [Shen and Patel 2008]
    - PE-HD: 6 g/bag
    - Bioplastic (starch-PCL): 8.1 g/bag
    - Bioplastic (PLA): 8.1 g/bag

The weights of bioplastic packagings in other studies are the same or less than those of conventional plastic packagings. Examples:

- Shopping bags: Weights per functional unit (FU) [Murphy et al. 2008]
  - PE-HD: 7.35 g/FU
  - Bioplastic (Mater-Bi, maize starch 50%-PCL 50%): 5.72 g/FU
  - Bioplastic (Octopus, PLA 60%-Ecofoil 40%): 7.7 g/FU

  (Ecofoil is a biodegradable fossil polyester; the problem of this comparison is that bags of different sizes were used, which somewhat distorts the weight comparison)
- Shopping bags: Weights [James and Grant 2005] quoted in [Shen and Patel 2008]
  - PE-HD: 6 g/bag
  - Bioplastic (starch-PBS/A): 6 g/bag
  - Bioplastic (starch-PBAT): 6 g/bag

  (Bioplastic blends have the same weights as the PE-HD bags; it is unclear which database this is based on)
- Cups/pots: Weights [Kauertz et al. 2011]
  - PS: 4.05 g/pot
  - PLA: 3.90 g/pot

  (Package content 115 g each; pots of identical shape)
- Cups/pots: Weights [Binder and Woods 2009]
  - PET: 15.5 g/cup
  - PLA: 13.6 and 14.4 g/cup

  (Volume 16 oz.)
- Cups/pots: Weights [Binder and Woods 2009]
  - PET: 11.5 g/cup
  - PS: 16 g/cup
  - PLA: 10 g/cup

  (Volume 500 mL each)
- Hinged bowls: Weights and density [Detzel and Krüger 2006]
  - PET: 19.9 g/bowl (density 1330 kg/m³)
  - PP: 16.9 g/bowl (density 900 kg/m³)
  - OPS: 15.2 g/bowl (density 1050 kg/m³)
  - PLA: 12.2 g/bowl (density 1230 kg/m³)

  (Fill quantity 500 mL each)

4.3.3 Ecological assessment of bioplastic packagings

Bioplastics in the packaging market first and foremost provide an alternative to the established conventional plastics. Therefore the focus of the assessment is on comparing bioplastic packagings and conventional plastic packagings.

4.3.4 Flexible film products

Waste bags

Biodegradable waste bags were studied in [Wellenreuther et al. 2009a]. The application studied were bags of equal volume for the residual waste collection under German local conditions. The bags were disposed via a WIP. The study finds that, in the reference period of the study, the biodegradable trash bags available in the market had higher adverse environmental impacts than trash bags made of fossil polyethylene (including greenhouse gas emissions).

This can be explained by the greater thickness of biodegradable trash bags compared to conventional trash bags. If we add the higher density of the bioplastics used, these bags clearly weigh more than the trash bags from conventional plastics. In addition, the bioplastic bags contain 40% to 70% of fossil raw materials.

They cause environmental loads in their production and disposal via WIP that are comparable to those of conventional bags. In addition, there are loads associated with cultivation and conversion of the biomass, which in particular affect Eutrophication and Acidification.

The study also examined future or optimization variants for biodegradable trash bags. They show that there is apparent potential for optimization. First and foremost, there are measures aimed at reducing the thickness of the films used and improvements in process engineering and treatment processes.

The study points out that a combination of various optimization steps, e.g. in areas such as material, design, and technological optimization, could bring the environmental impact of biodegradable trash bags (for residual waste collection) within the range of the environmental impact of conventional PE bags.

No detailed information was provided about the implementation time frame for the combined optimization measures. According to bioplastics manufacturers, these steps could be taken right away. But the plastics processors warned that biodegradable plastic films with reduced film thickness would show clear deficits in technological properties.

Carrier bags

[Murphy et al. 2008] and [Chaffee et al. 2007] examined biodegradable waste bags.

[Chaffee et al. 2007] studied the use of bags of comparable volume in the United States as an application example. They compared a PE-HD bag (5.78 g) with a biodegradable bag (15.78 g) made of a blend of 65% EcoFlex® (a fossil-based bioplastic), 10% polylactic acid (PLA), and 25% calcium carbonate. They assumed that 82.2% of both types of bags were disposed of in landfills and 13.6% through waste incineration. The remainder of the PE-HD bag is recycled, the remainder of the bioplastic bag is composted.

The study finds that plastic bags made of PE-HD have considerable environmental advantages over bioplastic bags (including greenhouse gas emissions). This can be explained to a major extent by the enormous weight difference between the two types of bags. The assumption in the study that the biodegradable bag is completely decomposed in the landfill and that the carbon it contains is completely released as CO2 or methane adds to the disadvantage of the bioplastic bag.

[Murphy et al. 2008] studied the use of carrier bags of comparable volume in the United Kingdom as an application example. They compared a PE-HD bag weighing 7.35 g/functional unit, a bioplastic bag made of Mater-Bi (50% maize starch and 50% PCL [fossil material]) weighing 5,72 g/functional unit, and a bioplastic bag as “Octopus” prototype made of 60% PLA and 40% Ecofoil (a fossil material) weighing 7.7 g/functional unit.

Please note that carrier bags of different sizes were included. This means that a different number of bags is needed to make up a functional unit.

Waste incineration and landfilling were assumed for the disposal of all bag types. Composting was assumed as an additional disposal method for biodegradable bags, mechanical recycling for the PE-HD bags.

The comparative results are derived in the study based on a single indicator value using the EcoIndicator method. The Mater-Bi bag achieved the lowest, the Octopus bag the highest environmental loads. The PE-HD bag is in between, except for the recycling scenario in which the PE-HD bag shows the best results in the overall comparison. The most favourable disposal option for the Mater-Bi bag and the Octopus bag are waste incineration with energy recovery for a single indicator result.

The single indicator results were dominated by two categories: Fossil resources (approx. 70%-80%) and substances with respiratory action (approx. 10%-15%). All in all, the documentation of assumptions and the presentation of the findings in the study are rather intransparent. No information is provided on the film thickness or technical comparison parameters (e.g. tensile strength), which would be helpful for comparing the functionality of the bags. The comparative graphic presentation of the results does not show the shares of the raw materials and the disposal processes and the credits awarded in the overall result.

Multilayer films

Multilayer films were studied in [Garrain et al. 2007] and [Hermann 2010].

[Garrain et al. 2007] examined 1m2 of film for packaging foods as an application example. The study does not give a clear geographic reference. A conventional film made of PP-PA6-PP (130-20-130 µ) and a biodegradable film made of PLA-modified starch/PCL-PLA (25-200-25 µ) were compared.

For disposal, waste incineration (without energy recovery) was assumed for the conventional film, composting for the biodegradable film. The study finds that the biodegradable film produces less environmental load in terms of climate change and fossil resources but a higher load for eutrophication and acidification.

The study was published as a specialist article and therefore provides limited documentation and transparence.

[Hermann 2010] examined 1m2 of composite film, differentiated by inner packagings and outer packagings, as an application example. Europe is given as geographic reference.

Inner packagings: Laminated films were compared in the following combinations:

- Polypropylene – hybrid laminate (MOPP= metallized oriented polypropylene)
- Polylactic acid laminates (PLA)
- Paper laminates

Outer packagings: Laminated films were compared in the following combinations:

- PLA

- Metallized PLA (MPLA)
- Bio-based polyethylene
- Paper laminates, e.g. with bio-based polyester (BBP) or ethylene vinyl acetate (EVA)
- Cellulose films

The weight per unit area was given for each composite film in the form of a bar diagram. The weights per unit area of the composites may differ greatly. However, no unique trend can be derived with respect to the influence of bioplastics on weights per unit area. Incineration, landfilling, composting, and fermentation were studied as disposal options.

The conclusions from this study can be summarized as follows:

Inner and outer packagings that contain PLA and are produced using the current technology do not pose any ecological advantages over the reference films. When the planned technologies for PLA films are implemented, PLA films will become comparable to the reference films. (Note: the data assumed for PLA production tendentially fall within the range of the eco-inventory for PLA published in 2010 according to [Vink 2010]).

Cellulose-containing films produced with today's process technology do not show any advantages with respect to environmental impact; this may change with future technological progress. The paper-BBP laminates, however, show the potential to reduce environmental impact compared to conventional films but they result in higher land use than other bio-based materials.

The ecological advantages depend on the polymer used and on the finished product (inner or outer packaging), and it looks like outer packagings hold greater promise than inner packagings, from an ecological point of view.

Under European conditions, films made of OPP and composite paper/OPP films represent the best choice for the Climate Change impact category. The PLA films and OPP films only become alike in the future projection.

The study advises to start with substituting petroleum-based outer packagings with bio-based materials such that investments can be made in this market segment and experience can be gained that would later serve to further improve the environmental impact.

The study was published as a specialist article and therefore provides limited documentation and transparence.

4.3.5 Shape-retaining packagings (cups/pots/bowls)

Cups/pots

Cups or pots were studied by [Kauertz et al. 2011], [Binder and Woods 2009], [Pladerer et al. 2008], [Ovam 2006] and [Bohlmann 2004].

[Kauertz et al. 2011] examined yogurt pots made of PLA and PS as an application example. Both pots can hold the same product quantity and weigh 4.05 g (PS pot) or 3.9 g (PLA pot). The local conditions of the German market apply. The German disposal mix for packaging waste was assumed: 80% of both types of pots will be thrown into the yellow bag while the rest is incinerated as residual waste.

PS pots in the yellow bag are primarily recycled in the pot fraction (64%) and the mixed plastics fraction (16%) while 80% of the PLA pots will become sorting remainders.

According to the results of the study, PLA pots have advantages over PS pots in the Climate Change, Consumption of Fossil Resources, and Summer Smog (POCP) impact categories. Disadvantages can be found in the Acidification, Terrestrial and Aquatic Eutrophication, and Human Toxicity (Fine Dust) categories.

If all environmental categories are assessed comprehensively (based on the UBA method), no LCA advantage or disadvantage can be derived for one of the two systems. Conclusions that are focused on the Climate Change and Consumption of Fossil Resources impact categories could be relevant in a strategic company context (here: at Danone). But overall ecological statements cannot be based on such findings alone.

[Binder und Woods 2009] studied cups made of PLA, PET, and PP for cold beverages. The cups have an identical volume and weigh 15.5 g (PET cup), 13.18 g (PP cup), or 14.4 g (PLA cup), respectively. A variant with 5% less weight was included for PP and PLA cups.

The local conditions of the U.S. market apply. All cup types were assumed to be disposed in landfills. Inert behaviour (virtually no release of greenhouse gases) was assumed for all materials including PLA.

According to the results of the study, PLA cups have advantages over PET cups in the Climate Change, Consumption of Non-Renewable Primary Energy, Consumption of Fossil Resources, and Summer Smog indicators. Disadvantages were found in the Acidification, Eutrophication, and Water Consumption categories.

The comparison with PP cups reveals about the same results, with one exception: The results are about level for summer smog.

In a comprehensive assessment (based on the UBA method), no LCA advantage or disadvantage can be derived for one of the two systems. These results cannot be directly applied to Germany because the disposal assumptions differ completely from the German local conditions. [Binder and Woods 2009] also make statements on the composting of PLA, wherein composting causes higher methane emissions and thus higher greenhouse gas emissions than landfilling. For the latter, inert behaviour was assumed for PLA, an assumption that is uncertain based on current knowledge.

[Pladerer et al. 2009] studied 500 mL cups made of PLA, PET, and PS for cold beverages. The cups are used for serving beverages during events. The cups weigh 11.5 g (PET cup), 16 g (PS cup), or 10 g (PLA cup), respectively. The weight of the PS cup is disproportionately high above the weights of the PET and PLA cups compared to other studies.

German local conditions were selected for the “Bundesliga football operation” group of events studied with respect to disposal and credits from waste incineration. In the basic scenario, the one-way cups were exclusively sent to waste incineration. It is striking here that an extremely high calorific value of 30 MJ/kg for PLA was assumed [16][Pladerer et al. 2009, p. 40].

Mechanical recycling at a collection rate of 80% was assumed as sensitivity scenarios for PET and PS cups. A scenario of 100% separate collection for composting was balanced for the PLA cup.

[16] According to EcoInvent-Report No. 13-I, the calorific value of PLA is 18.2 MJ/kg.

According to the results of the study, PLA cups have advantages over PS cups in the Climate Change, Consumption of Non-renewable Primary Energy, Consumption of Fossil Resources, Acidification, Fine Dust Emissions, and Summer Smog indicators. Disadvantages were found for Eutrophication (no difference was made between terrestrial and aquatic eutrophication).

The comparison with PET cups reveals about the same results, with one exception: The results are about level for acidification.

The good results of PLA cups with respect to acidification could be due to the high calorific value assumed and the resulting credits.

If assessed based on the UBA method, an LCA advantage could be derived from the basic scenarios for the PLA cup. Only the findings for the Climate Change impact category were represented separately in the recycling scenarios. Otherwise, results are only documented using the UBP 2006 single indicator method, which deviates considerably from the UBA method. It is apparent that the results for PET and PS cups improve greatly through recycling. Statements as to how the results of the comparison in the basic scenarios discussed above will change cannot be derived.

The PLA composting scenario results in an increase of greenhouse gas emissions compared to the basic scenario with waste incineration.

The study focuses more on the “UEFA Euro 2008” group of events studied in which cup systems were analysed and documented under the local conditions of Austria and Switzerland; these results were mainly analysed and documented using highly aggregated single indicator methods. The authors state in conjunction with the comparison of plastic one-way cups that the “environmental load from PLA one-way beverage cups is comparable to that of PET one-way beverage cups.”

[Ovam 2006] compared one-way drinking cups made of PLA with cups made of PP. The study did not provide information on comparative weights. Waste incineration or thermal recycling in a cement works were assumed for disposal. The region of geographic reference is Belgium.

According to the results of the study, PLA cups have advantages over PP cups in the Climate Change and Consumption of Fossil Resources impact categories. There are disadvantages in the Mineral Raw Materials, Acidification/Eutrophication, Ecotoxicity, Destruction of the Ozone Layer, Carcinogens, Inorganic and Organic Substances with Transpiratory Action impact categories.

For a future projection for the PLA cup, optimizations of the fermentation technology during PLA production and a weight reduction of the cup by about 20% were assumed. The PLA production facility was assumed to be in Europe for LCA purposes. The assumed future disposal options for the PLA cups were 90% fermentation and 10% incineration.

The future scenario results in a reduction in environmental impact from 10% to 60% for the PLA cup, depending on the category under review. Even if the differences in absolute results change, the pattern of advantages and disadvantages compared to the PP cup is mostly retained.

Composting PLA cups results in clearly reduced greenhouse gas emissions compared to incinerating them. (Note: This study provides no information on the degradation rate of PLA cups during composting, therefore this result cannot be critically evaluated).

[Bohlmann 2004] compared yogurt cups of the same size made of PLA (8.91 g) and PP (7.9 g). Impact assessment was limited to the Climate Change and CED indicators only. The study is completely unusable for a comparison of current packagings. However, it does contain an optimization analysis of PLA production which reveals that the efficiency of evaporation methods for biochemical processes (the fermentation process works in a highly diluted aqueous solution, for example) is of great relevance.

Hinged bowls

Hinged bowls were examined in [Detzel and Krüger 2006] and [Madival et al. 2009].

[Detzel and Krüger 2006] studied hinged bowls made of PLA, OPS, PP, and PET as an application example. All bowls hold the same product quantity but have different weights (PET bowl: 19.9 g; PP bowl: 16.9 g; OPS bowl: 15.2 g; PLA bowl: 12.2 g). The local conditions of the German market apply. The German disposal mix for packaging waste was assumed for disposal. It was assumed that 80% of all bowl types are thrown into the yellow bag while the rest is incinerated as residual waste.

It was further assumed that the PLA bowls collected in the yellow bag end up in the mixed plastics fraction and are primarily recycled energetically.

The study finds that the PLA bowls have advantages over all other systems in the Consumption of Fossil Resources, Climate Change, and Summer Smog categories. They have disadvantages compared to all other systems in the Acidification, Eutrophication (terrestrial), and Human Toxicity (PM10) categories.

Among the disposal options for PLA, the raw material recycling scenario (recovery of the monomers) shows the best results in the LCA while composting performs worst. The study assumes 95% degradation of the PLA carbon and its partial conversion into, and release as, methane.

[Madival et al. 2009] examined hinged bowls made of PLA, PS, and PET as an application example. All bowls hold the same product quantity but have different weights (PET bowl: 31.6 g; PS bowl: 24.6 g; PLA bowl: 29.6 g). All cup types were assumed to be disposed as follows: 23.5% incineration, 76.5% landfilling; based on the disposal conditions for household waste in the United States in 2005.

The study finds that the PLA bowl has advantages over the PS bowl in the Consumption of Non-Renewable Energy, Summer Smog, and Aquatic Ecotoxicity categories. It shows disadvantages in the Climate Change, Aquatic Acidification, Aquatic Eutrophication, and Organic and Inorganic Substances with Respiratory Action categories.

The PLA bowl has advantages over the PET bowl in the Climate Change, Consumption of Non-Renewable Energy, Summer Smog, Aquatic Eutrophication, and Aquatic Ecotoxicity categories. It shows disadvantages in the Aquatic Acidification, and Organic and Inorganic Substances with Respiratory Action categories.

PLA production

[Groot and Boren 2010] compared the production of PLA to various fossil polymers. The basis for comparison were production and waste incineration of one metric ton of polymer; the manufacture of packagings was not examined. The geographic reference is Thailand.

The study is therefore not suitable for a packaging comparison. An interesting aspect is that sugar cane is used as biomass raw material.

The study finds that PLA has advantages over the fossil polymers in the Consumption of Non-Renewable Energy, Climate Change, and Summer Smog categories. Disadvantages compared to fossil polymers were found for the Acidification, Eutrophication, Photochemical Ozone Formation (exception: PET), and Human Toxicity (exception: PET) categories.

A number of optimization options were studied.

- Use of a cultivated sugar cane variety with a high sugar yield (note: the average yield in Thailand is clearly less than in Brazil)
- Reduced fertilizer use
- Optimization of the evaporation and crystallization steps
- Experience-based improved know-how in fermenting, chemical separation technology
- Gypsum-free lactide production

Unfortunately, only results relating to the potential influence on climate change were reported: Even negative CO2 emission values can be achieved for the PLA polymer, depending on implementation level (note: the greenhouse gas values become positive if incineration is included).

4.3.6 Loose-fill

[Würdinger et al. 2002] compared loose-fill packaging materials made of foamed starch (bulk density: 12 kg/m3) and polystyrene (bulk density: 4 kg/m3) based on 1 m3 of material. Foamed starch was obtained from potatoes, wheat, and maize. German local conditions for the reference year 2001 were applied. The disposal mix of WIP and landfill that was common then was assumed for disposal. Disposal options for starch chips were composing, fermentation, and incineration in an optimized WIP. Mechanical recycling and optimized WIP or energetic recycling were considered for the EPS chips.

When comparing the “Primary Polystyrene” and “Maize Starch” loose-fill scenarios, the former shows advantages with respect to Climate Change, Diesel Particle Emissions, Ozone Depletion. The advantages of the starch chips lie in Fossil Resources, Cancer Risk Potential, Acidification Potential, and Ozone Formation Potential.

The study makes the following statement on the evaluation of biodegradability: “Composting clearly shows less favourable results in energy recovery. The findings make it very clear that biodegradability alone is not a criterion for the environmental compatibility of a material or product. Instead, it is decisive what disposal route it will take after use and how biodegradability affects the useful life and durability of the product.”

4.3.7 Bio-PE

[Liptow and Tillman] compared PE-LD from Brazilian sugar cane (biogenic PE) and from petroleum (fossil PE). The basis for comparison were production and waste incineration of 1 kg of polymer; the manufacture of packagings was not examined. The geographic reference for the potential use and disposal of PE-LD is Sweden.

The methodology applied in the study, attributional and consequential LCA[17] represents two very different approaches. The analysis of the influencing variables and the summary assessment of the study are made considerably more complex.

[17] Attributional LCA describes a given situation, frequently the current situation. All co-products are treated by the allocation method and leave the product system under review with their allocated environmental load.

The results in the basic scenario are as follows:

1. **Climate Change/Consumption of Fossil Resources:**

   (these two categories were highlighted in the study as being of special importance)

- Release of greenhouse gases and consumption of fossil resources were considerably lower for biogenic PE-LD than for fossil PE-LD. This was true for both the attributional and the consequential approaches.
- The results become inverse for the attributional approach if a direct and indirect land use change is assumed. This does not occur when taking the consequential approach, since the fossil CO2 emissions from waste incineration of the fossil PE-LD are counted in full here while the attributional approach allocates these to the recovered energy and not to the disposal process.

2. **Other indicators:**

- Acidification Potential:

  Attributional approach: biogenic PE-LD and fossil PE-LD are close together

  Consequential approach: clear disadvantages of biogenic PE-LD
- Eutrophication Potential: clear disadvantages of biogenic PE-LD
- Photochemical Ozone Formation Potential:

  Attributional approach: advantages for biogenic PE-LD

  Consequential approach: biogenic PE-LD and fossil PE-LD are close together

Variants were studied assuming bio-PE production in Morocco and fossil PE production in Sweden.

1. **Biogenic PE from Morocco vs. Brazil**

- Overall an improved environmental impact profile, especially due to the reduced transport distance; reduced values, primarily for the Acidification Potential, Eutrophication Potential, Photochemical Ozone Formation Potential environmental categories.

2. **Fossil PE production with the Swedish power mix**

- Overall an improved environmental impact profile, especially due to the low percentage of fossil energy carriers in the power mix.

The result diagrams in the study showed a cross-comparison of fossil PE (Swedish power) and biogenic PE, taking land use changes into account. In this case, fossil PE (Swedish power) had overall the most favourable environmental impact profile.

Consequential LCA claims that it allows a future-oriented view. Co-products are treated using the credit note system. The overall model becomes much more complex because this system requires spatial extension. Attempts were made to simplify the system with a few tricks, but these result in an implicit allocation decision.

For more information, see also: http://lct.jrc.ec.europa.eu/pdf-directory/ILCD-Handbook-General-guide-for-LCA-DETAIL-online-12March2010.pdf

4.3.8 Screening life cycle assessments for bio-PE and PLA

In addition to the literary reviews, IFEU performed two screening life cycle analyses to investigate the state of knowledge about a new bioplastic packaging material (packaging made of bio-PE) and current developments (use of lignocellulose waste for a PLA packaging) with realistic packaging examples for German local conditions. An assessment of current developments with reference to the German packaging market would not have been possible without these LCAs. The procedure and the findings have been described in Section 4.2.

The “Hinged Bowls” case study compared hinged bowls made of PLA to hinged bowls made of PS. Identical volumes and weights (15 g/bowl) were assumed for both. The disposal routes were analysed as in [Danone 2011].

Production from sugar beets or maize straw in Germany was assumed for PLA. We relied on data from [Reinhardt et al. 2007] for this purpose. In this study, PLA production was accounted for in the analysis as “sugar beet today” and “sugar beet in the future” and “lignocellulose today” and “lignocellulose in the future”, respectively. The data for “sugar beet today” should reflect the current technological possibilities well, while “lignocellulose today” probably reflects a very optimistic view of the current state of the art. [Reinhardt et al. 2007] give a target horizon between 2015 and 2020 for their future scenarios.

The “Film Product” case study compared a flexible film made of bio-PE and one made of fossil PE. 1 m2 of film with identical weight was assumed for both materials. 50% disposal in the yellow bag and subsequent recycling were assumed for disposal. 50% end up in waste incineration via residual waste (see also Fig. 12).

The bio-PE was assumed to be produced in Brazil from Brazilian sugar cane. The data used should reflect the current average situation of sugar cane conditioning and processing quite well. The production of bio-ethene and polymerization in this case study are based on proprietary IFEU data and data from process simulations according to [Liptow and Tillman 2009]. Modelling was based on a life cycle model for bio-PE production developed by IFEU on behalf of Coca-Cola GmbH.

4.3.9 Summary assessment

Flexible films

The analysed literature does not allow a general statement with respect to the ecological significance of bioplastic packagings versus conventional packagings. Bioplastic bags are often made of thicker films in practice, which may result in much higher weights and more material consumption than for conventional bags. In addition, these films contain 40% to 70% of fossil components, see [Wellenreuther et al. 2009a], used to set the required processing and application properties. This case is found in [Chaffee et al. 2007].

The combination of greater film thickness and fossil components is probably crucial for the fact that the bioplastic bags cause higher environmental loads (including greenhouse gases) than the conventional ones in these studies.

The situation is somewhat different in [Murphy et al. 2008]. The bioplastic bag made of Mater-Bi has a lower weight than the PE-HD bag, but this could also be due to different sizes. The Mater-Bi bag is bigger and therefore has a positive weight scaling effect if referred to the same functional unit. [Murphy et al. 2008] regrettably do not report film thicknesses. Assuming that both bags will be incinerated after use, [Murphy et al. 2008] give the Mater-Bi bag a better ecological rating. If recycling of the PE-HD bag is assumed, this bag gets the better ecological rating. Rating is based on a single indicator method and therefore hardly compatible with the German rating system [UBA 1999].

Bioplastic bags are in reality produced with the same film thickness as PE films. The weight per unit area of these films will probably still be about 30% above the weight of polyethylene films due to the higher density of starch and the other polyesters used.

The situation for multilayer films is clearly more complex because the weight per unit area varies considerably depending on the composite material used [Hermann 2010]. Overall ecological advantages of multilayer films made of or with bioplastics can neither be derived from [Hermann 2010] nor from [Garrain et al. 2007].

Films made of bio-PE do not differ in technological properties from conventional films. They are ecologically advantageous with respect to the emission of greenhouse gases and the consumption of fossil resources. But they also have apparent disadvantages with respect to acidification, eutrophication, and fine dust emissions. In an overall ecological context, the bio-PE films do not have a clear advantage.

A general assessment is difficult because environmental advantages and disadvantages of bioplastic film products versus conventional products can only be determined in comparative case studies. Too many factors have an influence on the performance of bioplastic films:

- What materials or material combinations are used?
- Which film properties are desired (tensile strength, barrier function, etc.)?
- What is the technological state of development of the product line (small plants, large plants)?
- Which conventional plastics are compared?

Our overall opinion is that bioplastic films representing the current state of the art do not have any overall environmental advantages over conventional films.

It should be noted, however, that various studies (especially [Wellenreuther et al. 2009a] and [Hermann 2010]) point to the considerable optimization potentials of bioplastic films. These include reduction of film thickness, improvements in the manufacture of the material or energy savings because they can be processed at lower temperatures. The optimizations at material level shown in Figure 14 have not been completely taken into account in the studies we analysed.

If the identified optimizations are fully implemented, bioplastic films could at least ecologically level with conventional materials or perform even better. It is unclear at the moment what time frames for implementation should be taken into account here.

Shape-retaining packagings

In the literature we analysed, the only bioplastic used is PLA. The material properties of PLA allow film thicknesses in this field of application that are below those of conventional plastics. Therefore, PLA packagings can be produced that weigh less than conventional packagings (see [Kauertz 2011], [Detzel et al. 2006], [Pladerer et al. 2008]). In contrast, the hinged bowls or pots/cups made of PLA studied by [Madival et al. 2009] and [Binder and Woods 2009] are heavier than those made of PS or PP, but lighter than the ones made of PET.

Four of the six studies analysed arrive at a relative uniform conclusion: The PLA packagings have advantages with respect to climate change and resource consumption and disadvantages with respect to acidification and eutrophication as well as impact categories used to rate toxicity potentials.

[Pladerer et al. 2008] did not find disadvantages with respect to acidification and eutrophication under German local conditions. But this only applies to waste incineration. Since the recycling scenarios are incompletely documented with respect to the impact categories examined, one cannot say whether these results would endure if PET and PS cups/pots were recycled. The main disposal route for [Madival et al. 2009] is direct landfilling, which is of no relevance in Germany. We have therefore refrained from evaluating this source.

In the opinion of IFEU, shape-retaining packagings made of PLA currently do not have any overall environmental advantage, but no disadvantage either. The results of PLA in packaging LCAs are characterized by the fact that they all relate to the production of Ingeo in the Midwest of the United States. The power used there has a high percentage of electricity generated from coal, which contributes to the relatively high environmental loads by sulphur oxide, nitrous oxide, and fine dust emissions. Other environmental loads originate from agriculture and contribute considerably to the Aquatic and Terrestrial Eutrophication and Acidification impact categories.

This is why the study by [Groot and Boren 2010], in which PLA is made from another biomass raw material and in another geographical region, was analysed in the literature review. But even this study shows very similar manifestations in the ecological comparison with fossil polymers if sugar cane is used as biomass. Various improvement options are proposed which would facilitate a considerable reduction of greenhouse gas emissions. Unfortunately, no information about implementation time frames is provided.

The screening life cycle assessments performed within this study show that the impact profile of PLA packagings could be improved considerably if crop residues (here residues from maize cultivation) were used, since environmental loads from biomass cultivation are virtually eliminated. This applies at least if the LCA is based on the rules of the European biofuel directive (RED). But this requires adequate efficiency of pulping and fermentation of the sugar from lignocellulose. When comparing a hinged bowl made of PLA with PS over the life cycle, there are no longer any disadvantages with respect to aquatic and terrestrial eutrophication, acidification, and fine dust emissions.

As the example of the screening LCA for sugar beets as raw material shows, an environmental impact profile can be achieved for hinged bowls even with “classic” biomass raw materials that eliminates many of the currently existing ecological disadvantages versus PS bowls if process optimizations (improved process yield, reduced consumption of energy and process chemicals when producing lactic acid from thick beet juice) are implemented. The remaining problem in this case will be aquatic eutrophication because this is mainly determined by sugar beet cultivation. Measures aimed at reducing emissions in agriculture will be essential in the future as well.

Implementation of the modelled “target technology” can only be expected in the medium term, no sooner than 2015 to 2020.

Composting and fermentation of biodegradable plastic packagings

Findings from the LCAs analysed regarding the various disposal options for bioplastic packagings will be summarized and evaluated with a focus on Germany.

Composting of biodegradable plastics or plastic packagings proved ecologically inferior to thermal utilization in several studies [Detzel and Krüger 2006], [Würdinger 2002] and [Murphy et al. 2008]. Composting and thermal utilization were close together in the [Hermann 2010] study if a low degradation rate of the plastics during composting was assumed. If a high degradation rate was assumed, composting showed less favourable results than thermal utilization.

In [Razza et al. 2008], composting (100%) of the biodegradable plastic flatware including food residues performed better than disposal of the PS flatware including food residues, which was subjected to a mix of landfilling (84%) + incineration (16%). But this study always viewed the biodegradable plastic flatware together with food residues. Since the PS flatware is probably mostly inert in the landfill, the results will be determined to a large extent by the emissions from landfilling the food residues (e.g. methane emission).

[Razza et al. 2008] is therefore not suitable for a direct comparison of disposal options for biodegradable plastics. The study shows, however, that targeted treatment of bio-waste is made possible under certain conditions with the help of biodegradable plastic packagings. The comparison of composting and a utilization mix that includes a relevant percentage of landfilling without pretreatment is not significant for Germany.

Composting as such should, by the way, be viewed as a physical (not a mechanical) utilization method. It is disputed whether composting of biodegradable materials is associated with a material recovery benefit. According to [Pladerer et al. 2008], PLA material does not contain any plant-available nutrients and does not contribute to building a soil structure. Composting PLA would therefore have to be considered disposal only. The manufacturers of biodegradable materials think that biodegradable materials participate in structure-building [Wellenreuther 2008b].

According to the LCA calculations by [Pladerer et al. 2008], composting shows less favourable results than waste incineration.

A major factor affecting the LCA result of composting bioplastics is the assumption of benefit achieved. Since bioplastics (other than bio-waste from households) do not contain any nutrients, they do not substitute mineral fertilizer. Its use could then be soil structure building (in principle, humification), which could be considered peat substitution. The assumed degradation rate is primarily relevant for eco-balancing purposes.

Since bioplastics that are certified biodegradable have to prove 90% degradation in a laboratory test, it would be obvious to assume a respective degradation rate during composting. A direct structure-building effect would then be negligible. In a waste balancing calculation of PLA based on such a degradation rate in [Detzel et al. 2006], composting proved ecologically less favourable than thermal treatment with energy recovery, thermal recycling in a cement works, or anaerobic treatment.

But the manufacturers of bioplastics point out that the degradation behaviour of bioplastics in a composting plant could be different from a laboratory test. In their opinion, a degradation rate of just about 50% similar to bio-waste was conceivable, which would enhance structure-building.

[Pladerer et al. 2008] also makes some statements on anaerobic treatment. According to them, various operators of fermentation plants refuse to treat PLA materials in their plants. They refer to the Lobau composting plant in Vienna as an example. They also point out that the fermentation of PLA materials would probably not yield more favourable results than incineration in a LCA because that would require high-quality use of the compost in addition to utilizing the biogas.

[Detzel et al. 2006] rate fermentation ecologically about level with thermal treatment. But they do point out that a more efficient biogas conversion of bioplastics still has to be proven in practical tests.

Open issues

Genetically modified organisms: Most studies we analysed did not indicate if genetically modified organisms (GMOs) are used as a biomass raw material for bio-based packagings (exception: [Kurdikar et al. 2002]). None of the studies topicalizes potential environmental impacts resulting from the use of GMOs in open land.

It can only be hoped that this will be given greater consideration in future life cycle analyses for bioplastic packagings.

Land use change: Some, but by far not all of the studies we analysed provide information on farmland required for supplying biomass for the bioplastic packagings under review. Except for [Liptow and Tilmann 2009] and [Kauertz et al. 2011], none of the studies analysed considers the aspect of direct or indirect land use change (LUC) and the associated problem of competition for areas in foodstuff cultivation.

It can only be hoped that the area problem is at least described in future life cycle analyses and that justifications are provided if land use changes were not considered in the LCA.

Additives: In the past few years, more and more additives were developed that are added to bioplastics to give them as wide a range of processing or use as possible. These additives have not been considered in the studies we analysed. The reason may be that additive manufacturers provide virtually no information on the composition and the manufacturing process. But this also applies to additives that are added to conventional plastics.

It would be desirable that additive manufacturers will make more information available in the future.

Water issues: Some, but by far not all of the studies we analysed provide information on water required for cultivating the supply of biomass raw materials. Water demand alone does not say anything about whether the withdrawal of water could cause an environmental problem or not (e.g. if water is withdrawn from areas with a water shortage or under water stress).

It can only be hoped that future life cycle analyses for bioplastic packagings will at least provide information on water demand. Ideally, this should also be addressed as part of an impact assessment.

5 Aspects of competition for areas

5.1 Scenarios on land requirements for bioplastics

The increased use of land for agricultural and forest products does not only affect environmental aspects such as interference with nature conservation, impacts on biodiversity or changed carbon sink conditions. Social aspects require increased attention since land used for agriculture and forestry is associated with specific property relations, production structures, and income situations depending on the country or region.

In this context, it should be pointed out that the use of renewable raw materials for energy and material purposes competes with foodstuff production.

This report focuses on the material use of biomass for biopolymers intended for packaging purposes in Germany. The question arises if and how any future subsidization policy under the Packaging Ordinance could cause or sharpen land use conflicts. We will begin with some considerations on the anticipated land requirement for bioplastics.

Land requirement is determined by the demand for, or utilization of, bioplastics. Various scenarios were assumed that are listed below:

1. Bioplastics use in the packaging sector in Germany in the 2009 reference year

   [Bio-Pack DE Status Quo]
2. Bioplastics use in the packaging sector in Germany (period from 2011 to 2015)

   [Bio-Pack DE Near Future]
3. Global production capacities for bioplastics in 2010

   [Bioplastics Capacities World 2010]
4. Global production capacities for bioplastics in 2015

   [Bioplastics Capacities World 2015]
5. Bioplastics use in the packaging sector in Germany with full utilization of the technical substitution potentials for conventional plastics

   [Substitution Pack DE (2009)]
6. Bioplastics use in the packaging sector with full utilization of the technical substitution potentials for conventional plastics production in Western Europe in 2007; without fibre production

   [Substitution Plast Western Europe (2007)]
7. Bioplastics use in the packaging sector with full utilization of the technical substitution potentials for conventional global plastics production in 2007; without fibre production

   [Substitution Plast World (2007)]

The bioplastics quantities for scenarios 1 and 2 result from the market data provided in Section 2.1. The global production capacities were taken from the information provided in Section 2.2. For scenario 5, the data on plastic use in the packaging industry (Sect. 2.1, Fig. 1) are linked to the data on technical substitution potentials by bioplastics.

The technical substitution potentials are listed in Table 2. The data was taken from [Pro-Bip 2009].

Table 2: Technical substitution potentials (without fibres and non-plastics) of conventional plastics by bioplastics (Source: Pro-Bip 2009)

	Starch blends	PLA	PHA	Cellulose films	Bio-PE	Bio-PP	Bio-PET	Bio-PVC	Total
PE-LD	8%		20%		72%				100%
PE-HD	8%	10%	20%		62%				100%
PP	8%	10%	10%	10%		57%			95%
PET:		20%	10%	15%			35%		80%
PVC			10%	10%				80%	100%
PS	8%	10%	20%	10%					48%

Table 3 lists the bioplastics quantities that would result if these potentials were fully utilized [Pro-Bip 2009].

Table 3: Bioplastics use in the German packaging market when substituting conventional plastics with bioplastics (basis: German plastic packaging market 2009)

	Starch blends [kt]	PLA [kt]	PHA [kt]	Cellulose films [kt]	Bio-PE [kt]	Bio-PP [kt]	Bio-PET [kt]	Bio-PVC [kt]
PE-LD	72.1		180.3		649.3			
PE-HD	40.1	50.1	100.1		310.4			
PP	41.6	51.9	51.9	51.9		296.1		
PET	0.0	64.9	32.5	48.7			113.6	
PVC	0.0		14.2	14.2				113.3
PS	9.1	11.3	22.7	11.3				
TOTAL	162.8	178.3	401.8	126.1	959.7	296.1	113.6	113.3

Table 4 lists the bioplastics quantities that would be required if the substitution potential of conventional plastics for the packaging sector by bioplastics were fully utilized.

Table 4: Bioplastics use if conventional plastics are substituted by bioplastics (Source: Pro-Bip 2009, edited by IFEU)

	Starch blends [kt]	**PLA [kt]**	**PHA [kt]**	**Cellulose Films [kt]**	**Bio-PE [kt]**	**Bio-PP [kt]**	**Bio-PET [kt]**	**Bio-PVC [kt]**
Substitution Plast Western Europe (2007)	2177	2575	5496	2452	9742	5361	1213	5148
Substitution Plast Global (2007)	10304	12270	26348	11953	45746	25593	45756	28224

For converting the bioplastics quantities into land requirement, an average yield of 2.5 metric tons of bioplastic per hectare is assumed in a simplified approach [Endres 2009], corresponding to an average land requirement of 0.4 ha/t. Potential future yield increases have been levelled in this compounded approach.

Table 5: Quantities and land requirement of the various bioplastics scenarios

	Bio-Pack DE Status quo	**Bio-Pack DE Near Future**	**Bioplastics Capacities World 2010**	**Bioplastics Capacities World 2015**	**Substitution Pack DE (2009)**	**Substitution Plast Western Europe (2007)**	**Substitution Plast Western Europe (2007)**
Kt	5.5	21	725	1,709	2,352	34,164	165,864
1,000 hectares	2.20	10.4	289	684	941	13,666	66,346

The current production capacities for bioplastics are about evenly distributed across the regions of Europe, North America, South America, and Asia/Oceania. Trade with bioplastics for the packaging sector is also global. This is demonstrated by the supply chains for the packagings on which the life cycle analyses mentioned here are based.

Due to the relevance of the global supply chains and globally distributed production capacities, land use reference will be made to global land use herein. Figure 32 shows the current land use divided by forest and agricultural areas and the share of the developed countries and the developing countries. In total, an area of 8,727 million hectares is used for agriculture and forestry.

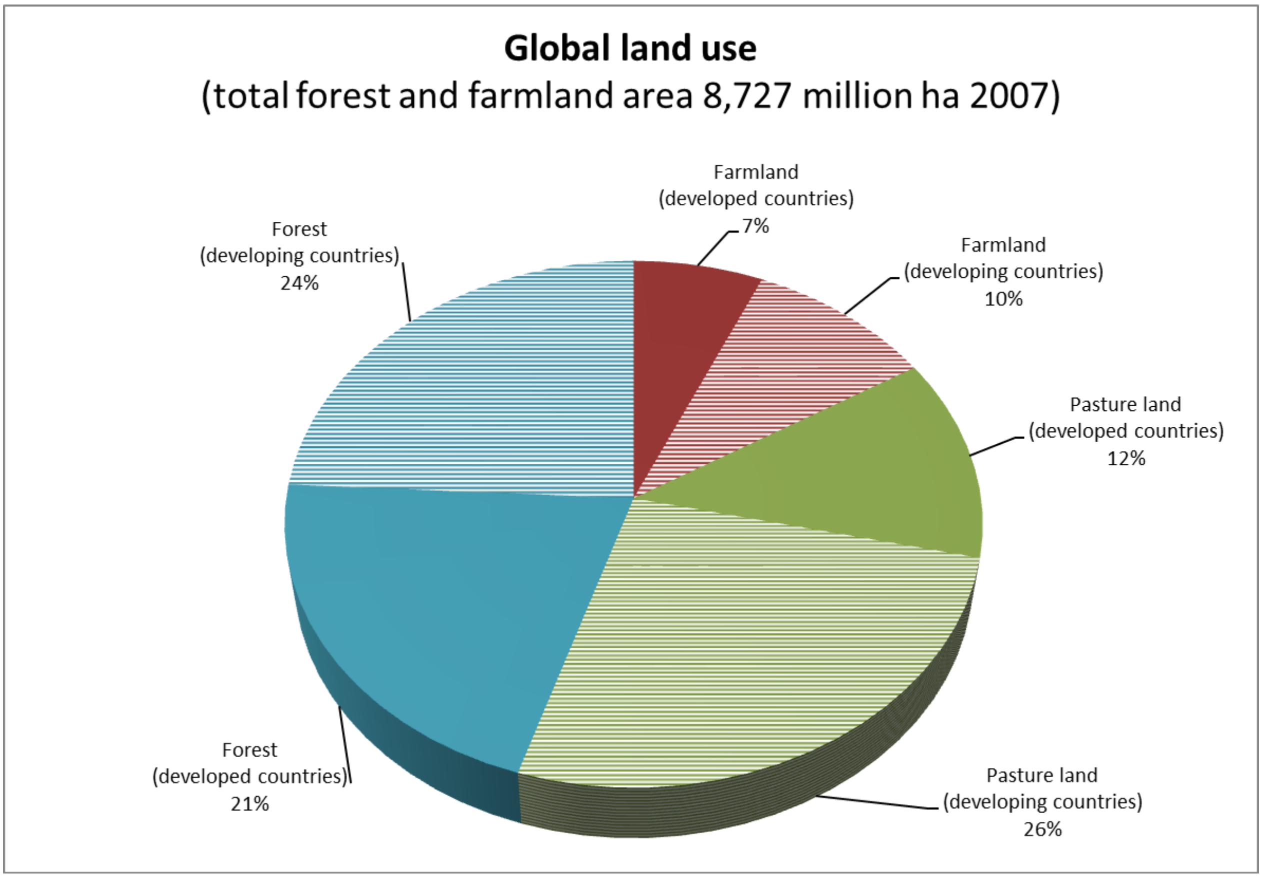

Figure 32: Distribution of global forest and agricultural areas, 2007

Source: Edited by IFEU based on [FAO 2009]

It appears that at present the biomass for the bioplastics virtually completely originates from cultivated biomass but we cannot determine the share of farmland in developing countries based on the data available. The following diagram shows the land requirement for the bioplastics scenarios in relation to the global farmland and in relation to the farmland in developed countries (Figure 32).

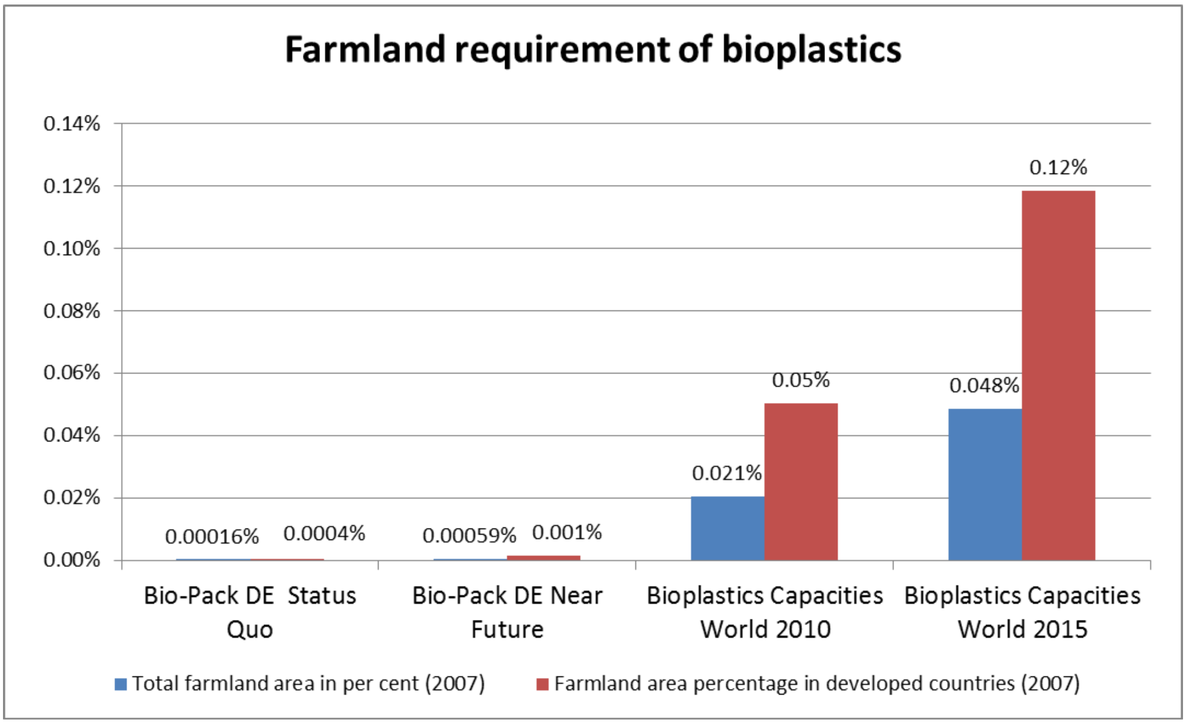

Figure 33: Land requirement of bioplastics in relation to global farmland

Source: Edited by IFEU

The land requirement caused by bioplastic packagings sold in Germany kin the status quo and in the near future makes up an extremely low percentage (less than 0.001%) of the global use of farmland (Figure 33). If we consider the current global production capacities for all bioplastics, these require 0.02% to 0.05% of the global farmland.

If the plastic packagings used in Germany, that is, both conventional and those made of bioplastics, were substituted by bioplastic to the extent technologically possible, the land requirement would be less than 1% of the global farmland (Figure 34). Mentionable to considerable percentages between 1% and 12% of the global farmland would be required if the Western European or global plastic demand were substituted.

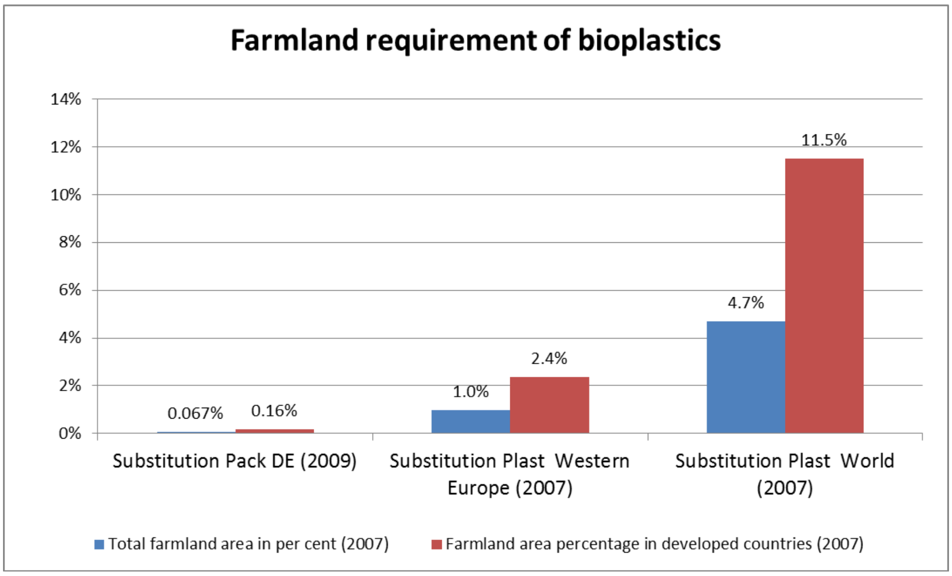

Figure 34: Land requirement of bioplastics in relation to global farmland

Source: Edited by IFEU

5.2 Land requirement for biofuels

The current discussion on competing uses is primarily focused on biofuels. Figure 35 differentiates global farmland use by general use categories. The global land requirement for biofuels is 25 to 30 million ha [de Greef 2009] or [BMVBS 2010] and thus makes up about 2% of the global farmland.

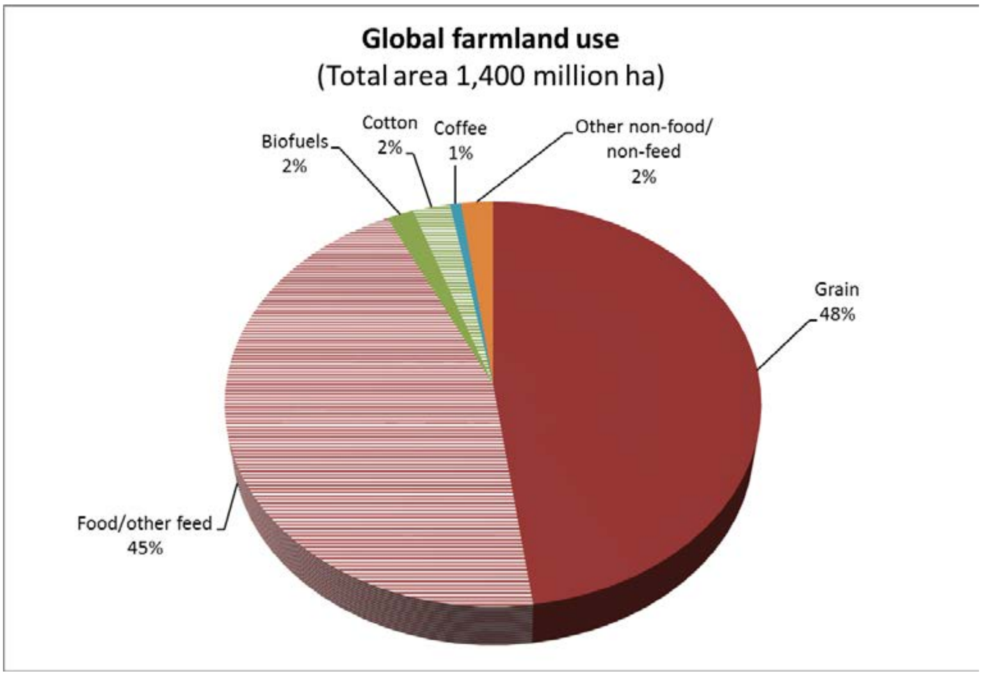

Figure 35: Use of farmland areas by categories, 2007

Source: Edited by IFEU based on [FAO 2009], [de Greef 2009]

The farmland requirement would increase if the existing biofuel targets were implemented. This can be seen in Figure 36.

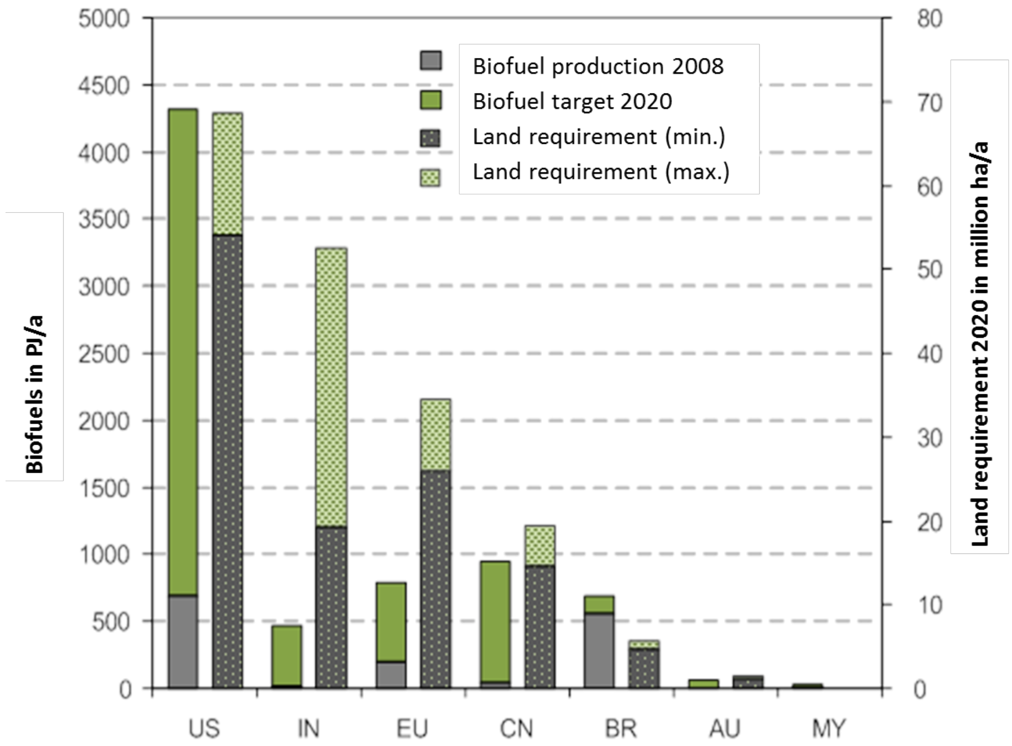

Figure 36: Biofuel targets and current production

Source: German Biomass Research Centre (DBFZ) 2009

The land requirement would increase to 120-180 million ha/a by 2020. This would be 8% to 13% of the global farmland. The data in Figure 36 is based on estimates by the German Biomass Research Centre (DBFZ) in Leipzig using worldwide biofuel targets provided by the International Energy Agency (IEA).

5.3 The "dinner plates to fuel tanks" discussion

The proportion of land use for biofuels of 2% mentioned above seems to be relatively small at first glance. However, biofuel production and use has come under severe criticism. It should be noted that this figure is the result of an enormous increase in production within just a few years.

The global production of bioethanol as a fuel has tripled from 2000 to 2007 and reached 52 billion litres (~1.2 exajoules [EJ]). The largest producers are the United States (51%, from maize) and Brazil (36.5%, from sugar cane). The share of the European Union of 4.4% (from sugar beets and wheat) is considerably less. The global production of biodiesel has increased tenfold from 2000 to 2007 and reached 10.2 billion litres (~0.32 EJ) [WGBU 2008]. Bioethanol is also an essential basic chemical for the new generation of bio-based bioplastics such as bio-PE and bio-PET.

The prices for agricultural products have risen in the same period. For example, food prices have increased on average by 83% between 2005 and 2008 [WGBU 2008]. [WBGU 2008] quotes various estimates regarding the influence of the increased demand for biofuels on the price increases observed: the U.S.

Department of Agriculture sees an influence of 2-3%; the World Bank, in contrast, assumes that the influence is 75% [Mitchell 2008]. The International Food Policy Research Institute (IFPRI) thinks that wheat prices are influenced at a rate of 30% by the demand for biofuels; the OECD speaks of an influence of 5% for wheat, 7% for maize, and 19% for vegetable oils.

[OECD Outlook 2011] mentioned the following aspects as key factors influencing the volatility of the prices for agricultural products:

- Weather conditions and climate change
- Stock reserves (they have diminished severely in the past few years)
- Energy prices, especially the oil price
- Exchange rates
- Increasing demand (factors: increase in purchasing power in emerging countries, population growth)
- Pressure on supplies (e.g. declining yields, availability of water)
- Trade restrictions
- Speculation (food trading at futures exchanges)

[WBGU 2008] considered the data basis generally as uncertain: This made it difficult to estimate future developments with respect to the influence of biofuels. While the extension of bioenergy production will presumably gain increasing influence on food prices, the numerous studies did not allow quantification of the complex effects.

The most recent study by [IPFRI 2011] confirms previous findings that a relevant percentage of additional land use change is required when the political biofuel targets of the EU are implemented. If that is translated to the greenhouse gas balance, more than two thirds of the savings achieved versus fossil fuels would be lost. The results are different dependent on the agricultural product. While relevant growth rates for sugar cane (ethanol) appear to require little additional land, the results for oil plants are much less favourable.

Even if connections between additional cultivation and displacement effects in food production are only described with reference to models and associated with accordingly great uncertainty, and even if they can only partially attributed to the biofuel boom, there is no doubt that an increase in demand for biofuels – under otherwise identical boundary conditions (same productivity, same food demand, etc.) – will result in short-term shortages that may cause a rise in prices. This applies in principle to bioplastics made of cultivated biomass for the medium term.

Another important finding of [IFPRI 2011] should be mentioned when considering bioplastics. The study shows that the effective demand for biomass is a decisive factor influencing the occurrence and extent of indirect land use change. The magnitude of a specific "ILUC factor" is the greater according to these modellings the greater the demand and is therefore not linear. If the potential demand for biomass is lower (e.g. lowering of the rates), the specific value for ILUC decreases as well. This should be kept in mind when evaluating bioplastics that have much smaller volume flows than bioenergy, as has been shown above.

All in all, demand pressure will arise in the future due to population growth and changed eating habits, especially the global increase in meat consumption. Meat needs much more area than crops for the same amount of energy. Today, pasture land and farmland for feed uses already make up 80% of the global agricultural land use [WBGU 2008].

It can be anticipated that the increased biomass demand will ultimately trigger an increase in supply. This will probably result in intensified farming and an expansion of farmland areas (and thus direct or indirect land use changes), as especially [IFPRI 2011] shows.

[WBGU 2008] quotes various sources for the last point: One forecast assumes additional conversion of areas into farmland in the amount of 500 million hectares until 2020 (presumably mostly from brownfield land, a smaller part from forests). This is expected to take place mainly in Latin America and in sub-Saharan Africa. The Food and Agriculture Organization of the United Nations (FAO) is quoted with a projection on the expansion of global areas for food production of 120 million ha until 2030.

[Wahmhoff 2009] mentions that there are 400 million ha of brownfield land in the world (50 million ha of which are in Russia). But he also indicates that global farmland area perhaps cannot be increased without immense ecological cost.

The scenarios calculated in [BMVBS 2010] are of interest in this context. This study estimates global farmland availability and biomass potentials based on four scenarios (Figure 37).

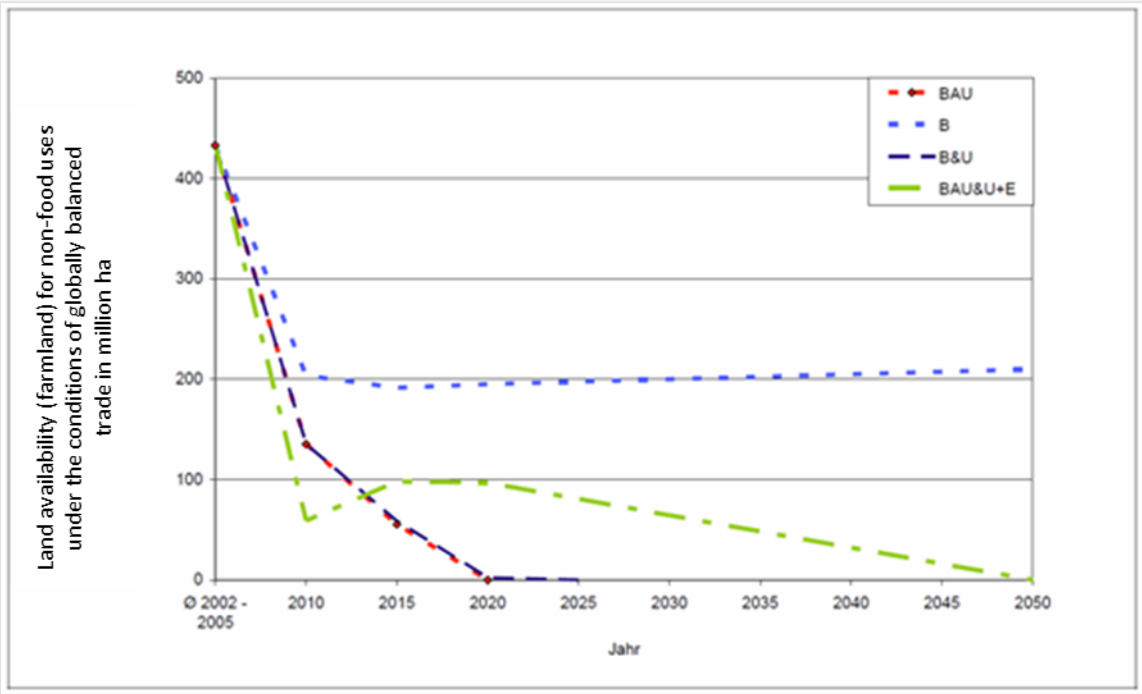

Figure 37: **Global land availability (farmland) for non-food uses under the conditions of globally balanced trade**

Source: BMVBS 2010

The abbreviations for the scenarios shall be read as follows (see also the list of basic assumptions of the scenarios in Appendix IV):

BAU (Business as usual): Forward projection of short and medium term trends

B (Bioenergy scenario): The energetic utilization of biomass is intensified. Investment results in further yield increases, expansion of farmland areas, and increased cultivation of high-yield crops

B & U (Bioenergy and Environment): Bioenergy with increased environmental and nature conservation restrictions

BAU & U+E: Business as usual with increased environmental and nature conservation restrictions plus diet change (less meat consumption)

An underlying condition of all scenarios is the assumption of globally balanced trade that ensures global food security. Areas are primarily designated for food production. Only the remaining areas will be available for agricultural biomass that can be utilized energetically.

According to Figure 37, the BAU scenario, i.e. no special increase in yields and expansion of farmland areas, will leave no more areas for agricultural biomass that can be utilized energetically, beginning in 2020. If one assumes that the interests of environmental protection and nature conservation are also taken into account, but on the other hand meat consumption declined sharply (BAU&U+E), available land would steadily decline down to zero until 2050.

Only the Bioenergy scenario (B) provides 200 million hectares in the long term. But the interests of environmental protection and nature conservation would barely be taken into account. If these are fully taken into account (see: B+U), the downward trend in available land is similar to the BAU scenario.

Figure 38 shows the potential energy derived from agricultural biomass resulting from the scenario assumptions. About 16 EJ as from 2020 and about 22 EJ in the long term will be available in the Bioenergy scenario only. Main biomass supplies would come from maize and sugar cane, which could also be used to supply starch and raw material for bioethanol production to produce bioplastics. In the long term, soy beans and oil palms could be added as relevant biomass supplies.

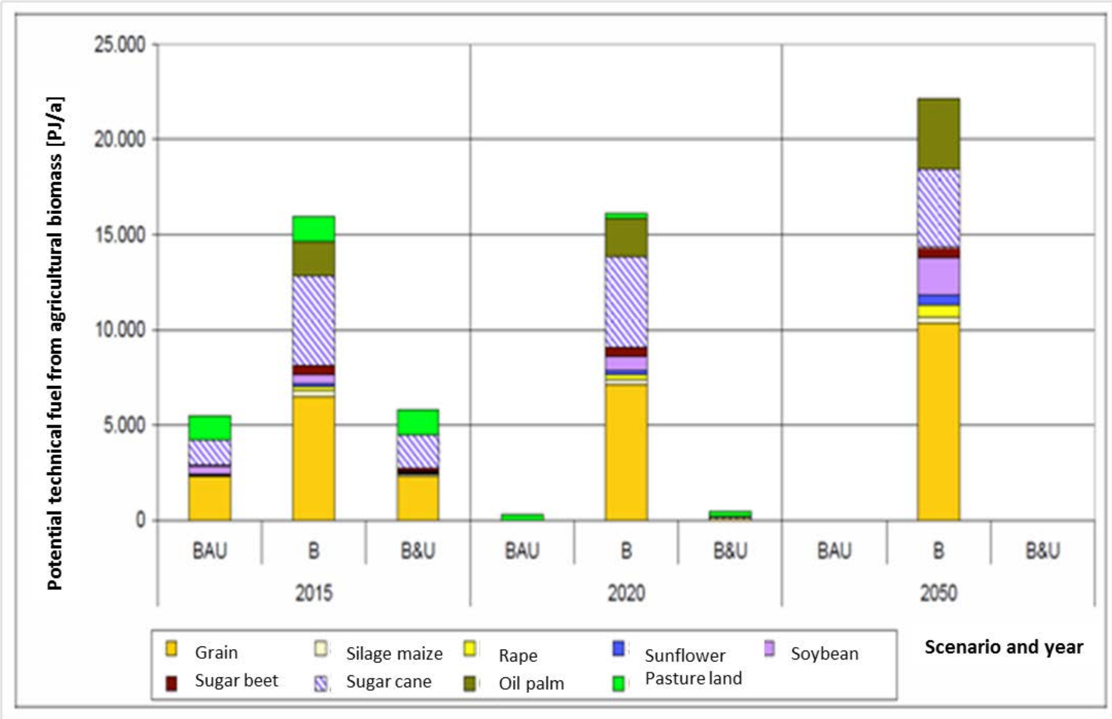

Figure 38: **Potential technical fuel from agricultural biomass in 2015, 2020, and 2050, BAU, B, and B&U scenarios with trade balancing, itemized by the various crops**

Source: BMVBS 2010

These figures do not include forestry production and the use of waste and recycling material. According to [WWF 2009], the global technically sustainable potential is between 80 and 170 EJ per year; about 50 EJ would come from waste and recycling material.

These figures show that the global food supply will result in considerable extra demand for cultivated biomass (directly or indirectly via meat consumption). Additional demand for non-food uses will therefore most probably result in price increases.

Based on a research project on biofuels [UBA Texte 34/2009], the Federal Environmental Agency has arrived at the following conclusions [UBA 2009b]:

“It was demonstrated that most of all increased biofuel use is limited by the scarce farmland resource and may not result in relieving the climate but in aggravating climatic problems from a specific quantity onwards. The world population, which continues to grow, leads to yet another per-capita scarcity of globally available land.”

5.4 Conclusion regarding bioplastics

It is hardly possible to provide a valid evaluation of the demand effect caused by bioplastics in general and bioplastic packagings in particular based on the information discussed above. The most important cultivated biomass types for packaging uses of bioplastics are maize, potatoes, and wheat as well as sugar cane, in the medium term presumably sugar beets as well. If we take the production capacities planned for bioplastics for 2015 as a reference variable, we do not anticipate a particular demand pressure by bioplastics in the short term.

The situation will aggravate in the long term, however, if global polymer production will be based on biogenic carbon chemistry in the future. The bioplastics manufacturers want to counter this by increasingly using waste residues as a raw material base. Such statements were also made in our interviews of market players. This requires the development of economically viable technologies for the efficient pulping of sugar from lignocellulose.

In the years to come, the demand for agricultural biomass will be much more characterized by biofuel production than by bioplastics production. 120 million hectares of farmland will be needed for implementing the global biofuel targets up to 2020 alone. Even if the global bioplastic production were to double from the capacity forecast for 2015 of 1.7 million metric tons to 3.4 million metric tons, the farmland requirement of 1.37 million hectares (approx. 0.1% of the global farmland area) would clearly fall below the land requirement for biofuels.

At any rate, biomass production for bioplastics must meet the same sustainability requirements as that for biofuels, in analogy to the Renewable Energy Directive (2009/28/EC). The sustainability requirements stipulated there are:

- At least 35% reduction in greenhouse gas emissions compared to fossil fuel
- Exclusion of areas that used to be primary forest, other forest, biologically diverse pasture land, wetlands, peat bogs (no-go areas) before 2008
- Good professional practice (cross compliance, in the EU)
- A mass balance method shall be used to prove compliance along the process chain. Proof is provided through a certification system.

In addition there are reporting duties on:

- Impact on soil, water, and air
- Water availability (e.g. indications of water scarcity)
- Implementation of the fundamental work standards of the International Labour Organization (ILO)
- Compliance with the Washington species protection treaty (CITES treaty)
- Compliance with the Cartagena Protocol on the implementation of the Convention on Biological Diversity

It should be kept in mind that the conversion of tropical forests used to be the primary source for new farmland areas in the 1980s and 1990s. Pasture land and managed forests are currently the main sources for the expansion of farmland, followed by (descending order) savannah, grassland, and primary forests [B&FN 2011].

Especially the criterion of no-go areas – protected areas where agricultural use is excluded per se – can already be applied directly to bioplastics. The pilot project by Danone should be mentioned in this context: in collaboration with the WWF, they strive for sustainability certification in accordance with the International Sustainability and Carbon Certification (ISCC) system that the EU has recently acknowledged as RED-compliant.

If the EU Commission should extend the requirements listed above by an “Indirect Land Use Change” (ILUC) component, this should similarly applied to biomass production for bioplastics. It is completely undecided at present what this component could look like. A decision is expected in 2012. It should be noted, however, that the clearly smaller demand effects of the bioplastics compared to bioenergy cannot nearly induce such extensive indirect effects as the econometric model calculations by IFPRI and others on biofuels suggest. But it will only be in exceptional cases that differentiation with respect to later use (energetic, material, food/feed) can be made at the cultivation level in a common biomass raw material market. This is why equal treatment in evaluation is justified in principle.

6 Conclusions and recommendations

This chapter is structured as a question-and-answer approach in this report. An attempt is made to discuss central issues of the research project and on the political treatment of bioplastics within the German Packaging Ordinance in a highly focused manner.

The questions:

1. What is the current market situation for bioplastics in Germany (reference year 2009)? What other developments can be expected in the future?
2. What is the current situation with respect to the disposal of bioplastic packagings (reference year 2009)?
3. What could the disposal situation for bioplastic packagings look like in the future?
4. Has the special regulation of the Packaging Ordinance promoted the market development of bioplastic packagings in Germany?
5. What obstacles exist for the market development of bioplastic packagings in Germany?
6. Is there still a need for a special treatment of bioplastic packagings within the Packaging Ordinance?
7. Is a special treatment of bioplastic packagings justified from an ecological point of view?
8. Could continued special treatment of bioplastic packagings result in adverse ecological and social impacts?
9. How would a continued special regulation have to be designed?

1. What is the current market situation for bioplastics in Germany (reference year 2009)? What other developments can be expected in the future?

In the reference year 2009, bioplastic packagings had a maximum share of 0.5% in the German plastic packaging market. Biodegradable packagings made of starch blends and packagings made of PLA or PLA blends were predominant. The blends contained biodegradable fossil components in addition to the bio-based materials mentioned.

Flexible films and loose-fill materials were used most widely. A smaller portion of bioplastic packagings were cups and bowls made of PLA and up to 5% of fossil additives. The fossil components of the loose-fill packaging materials made up an estimated 13% and of the flexible films between 40% and 50%.

As far as we know, there were no biodegradable beverage packagings in the market in 2009. But beverage bottles made of bioplastics will win a greater market share in the near future. Partially or fully bio-based materials (bio-PET, bio-PE) will be utilized, but these are not biodegradable. Their properties are virtually identical with those of the conventional plastics from the same material. After they are placed on the market, they can no longer be distinguished from similar conventional packagings[18].

[18] Differentiation presumably only feasible using C14 measurements.

It is expected that the overall share of bioplastic packaging in the German plastic packaging market will increase to roughly 1%-2% in the period between 2011 and 2015. Cups, pots and bowls will see a large increase in addition to beverage bottles. Flexible films are also expected to grow. Bio-PE will presumably be used in this field of application as well.

There is also a trend towards bio-based but non-biodegradable plastic packagings made of bio-PE or bio-PET. Among the shape-retaining PLA packagings, the aspect of biodegradability seems to lose significance in the market assessment of the products in favour of a strategy towards raw material or mechanical recycling.

The outlined trend could strengthen moderately as early as in the period from 2011 to 2015 if the bioplastic packagings introduced by branded companies trigger a market impulse. An increase in bioplastic packagings is also anticipated beyond the year 2015.

Material availability will be a major prerequisite for this. On the other hand, the plastic packaging market will have to rely on a predominantly biogenic carbon network in view of the imminent long-term scarcity of petroleum.

2. What is the current situation with respect to the disposal of bioplastic packagings (reference year 2009)?

Bioplastic packaging waste is mainly incurred in private households. It is either thrown into the yellow bag, regular waste, or green waste.

Further considerations on disposal routes for bioplastic packagings are based on the premise that consumers treat these mostly like they treat conventional plastic packagings. We assume that special handling of bioplastic packagings by consumers can be found for biodegradable bags that are also used for collecting green waste. It can be expected that these will be thrown into the green waste bin together with their contents.

In terms of collecting recyclables, we assume that 50% of the flexible films and 80% of cups/bowls are thrown into the yellow (recycling) bag. The residual amount would then get into waste treatment through WIPs or composting plants; it is hard to estimate the percentages. Eventually, many of the bioplastics collected with the biowaste will be disposed of in an incinerator because they would be sorted out in most German composting plants.

Used bioplastic packagings were not sorted into target or mono-material fractions in the 2009 reference year. It is assumed that they are largely recycled into refuse-derived fuel together with conventional plastics and ultimately utilized energetically in cement works.

All in all, knowledge about the disposal situation of bioplastic packagings is very limited. This requires improvement, since the current situation makes targeted waste management much more difficult.

One can certainly say that a high percentage of bioplastic packagings was recovered in one way or another, but predominantly via waste incineration plants with energy recovery and in part by thermal recycling, most of all in cement works.

Composting did not gain a relevant share as a disposal route for used bioplastic packagings, which was in contrast to expectations initially raised.

3. What could the disposal situation for bioplastic packagings look like in the future?

The following developments could occur in the years to come:

A. Non-biodegradable bioplastic packagings made of bio-PE, bio-PP, and bio-PET are treated like conventional plastics of the same material and take the same disposal routes. They will therefore also be mechanically recycled.

B. There is the general option of material-specific separation as part of a polymer detection process for biodegradable packagings or packaging components from mono-materials (currently mostly PLA and PHA packagings, if any). The separation devices must be set to a respective positive screening for this purpose. Such a separation is currently not performed in reality because the material quantities are too small. This will certainly change in the future; however, we cannot provide a time frame.

C. No targeted development towards material recycling is anticipated for biodegradable packagings from material blends, mainly starch-based and PLA-based copolymers and cellulose-based multilayer films in the near future. These materials vary in starch content, and they contain different types of starch (maize starch, potato starch), various fossil copolymers (PBAT, PVOH), and various additives. They are generally quite heterogeneous and therefore not very suitable for positive substance group-specific screening and material recycling processes.

   These packagings would have to be disposed in a targeted manner via the bio-waste route to give greater weight to composting and fermentation. But this requires a targeted information effort on the part of, or including, the communities to prevent undesirable increased contamination of the bio-waste with non-biodegradable plastics. The revised version of the Biowaste Ordinance could give an impetus here, but this will be rather modest in our opinion.

   It should also be kept in mind that the ecological position of composting is much less favourable than thermal recycling under German local conditions. At best, efficient fermentation with subsequent composting could trigger a reassessment and reduce the obstacles that result from an unfavourable ecological evaluation. But there is still a great need for research and technological improvement.

4. Has the special regulation promoted the market development of bioplastic packagings in Germany since the 5th amendment of the Packaging Ordinance entered into force?

The market data assessed in Section 2.3 of this report give rise to the assumption that the impetus given by the special regulation has been rather marginal until 2009. According to statements from manufacturers and users of biodegradable carrier bags, saving the licencing fee has been a crucial factor for the market acceptance of this product group.

The special regulation probably also had a positive effect on the market acceptance of shape-retaining products that consist exclusively of PLA (i.e. no sealing foils made of conventional, non-biodegradable plastics).

But the positive effect in these market segments had hardly any effects on the overall packaging market.

5. What obstacles exist for the market development of bioplastic packagings in Germany?

The higher market price of polymers has repeatedly been mentioned as a major market obstacle. The special regulation has not worked for many biodegradable plastic packagings, market participants say. Therefore, such packagings could not enjoy the exemption from the licencing fee and save the costs involved. There are also statements that the licencing fee for plastics has dropped in the past few years. This would have reduced the cost leverage envisaged with the special regulation of the Packaging Ordinance anyway.

There seems to have been a similarly great obstacle in that the technological properties of the bioplastics were inferior to those of the conventional plastics. According to the market participants, considerable progress has been made in this respect in the past 2-3 years.

New biodegradable additives were developed with which factors such as heat resistance, processability, barrier properties, and physical and mechanical parameters of the packagings produced can be set as required by the intended use. The differences between biopolymers and conventional polymers were clearly reduced, and they were working on improving the factors mentioned.

Some market participants see another obstacle in the disposal situation they rate unsatisfactory, especially the highly limited access (regulated in the Biowaste Ordinance or community rules) of biodegradable plastic packagings to the green waste bin. Because biodegradable packagings do not end up in the biowaste flow but in the flow of recyclable materials, there are ongoing discussions about their role as an interference or even risk to the established routes of material recycling. This can result in rejection among decision-makers, especially among traders, and the otherwise positive perception of biodegradable plastic packagings could be reversed.

6. Is there still a need for a special treatment of bioplastic packagings within the Packaging Ordinance?

We would first have to discuss the goal to be achieved by a special treatment. The Packaging Ordinance is meant to serve waste management goals in conjunction with the use of packaging. Exempting biodegradable packagings from the licencing fee is primarily meant as an instrument to help establish recycling routes outside the yellow bag.

But this can basically just mean treatment by composting or fermentation similar to or together with other organic waste. This would be a treatment for which the specific characteristics of these materials are geared. In addition, these treatment options are cheaper than collection in the yellow bag. This regulation indirectly contains a market stimulation instrument because the reduced energy costs compensate for the higher material costs.

The present study has found that the expectations associated with the special regulation have not come true. Bioplastic packagings were overwhelmingly thrown into the yellow bag. There has been no market breakthrough. Exempting biodegradable beverage packagings from deposits did not work either because there are no such packagings in the German market. In view of this situation, it is hardly possible to advocate a continuation of the special regulation in the Packaging Ordinance.

It has been pointed out time and again that the limited access to the biowaste bin has obstructed the establishment of a specific disposal route. This restriction will probably be lifted with the revised version of the Biowaste Ordinance. It may be too late though, because the packagings that have recently invaded the market are made of bio-based materials identical to conventional plastics and will take the disposal route of the yellow bag.

Among the three criteria mentioned above (question 5) of price, performance profile, and disposal, only the price can be an obstacle for the new bioplastic materials versus conventional plastic packaging. But this does not require action in terms of a special waste treatment provision under the Packaging Ordinance.

7. Is a special treatment of bioplastic packagings justified from an ecological point of view?

General statements cannot be made in this context. It is clearly visible that the environmental impact profiles of many bioplastics have considerably improved since their initial development and that there is still considerable room for optimization.

Bioplastics, with the proviso that they are mostly or fully bio-based and that they have a similar packaging performance as conventional plastics (e.g. similar weight, similar mechanical properties), frequently show better results in a life cycle analysis with respect to greenhouse gas emissions and consumption of fossil resources. On the other hand, the same bioplastic packagings are frequently less favourable with respect to other environmental categories such as acidification, aquatic and terrestrial eutrophication. From an overall ecological point of view, these bioplastics are not necessarily better than conventional plastics but rather level with them.

Bioplastic packagings whose properties are mostly geared towards composting typically contain larger percentages of fossil copolymers. In addition, their packaging performance is often limited. LCA results of this group of bioplastic packaging therefore may even show an unfavourable overall environmental performance as compared to the conventional competitors.

Any special treatment should be targeted at promoting bioplastic packagings that potentially can have overall ecological advantages over conventional plastic packagings. Primarily, there is need for action with respect to biomass supply (selection of adequate crops, improvement of farming operations, use of residual biomass or lignocellulose) and the processes for biomass conversion where a clear increase in energy efficiency has to be achieved.

8. Could continued special treatment of bioplastic packagings result in adverse ecological and social impacts?

The Millennium Development Goals of the United Nations include two goals, “elimination of extreme poverty and hunger” and “ensuring environmental sustainability” which could be impaired by increasing competition for farmland use.

But at the focus of this debate are biofuels, not bioplastics. Between 8% and 13% of the global farmland that is currently available would be needed if the global biofuel targets until 2020 were implemented.

In comparison, less than 0.001% of the global farmland is going to be used for bioplastic packagings in Germany in the years to come. But the German market for bioplastic packagings should not be viewed in isolation. A look must be taken at the global bioplastics market. The land requirement for this market could be around 0.1% of the global farmland in 2020.

One could argue that, as the farmland resource is becoming scarce, any additional demand aggravates the problem. This is why we need mechanisms as soon as today that ensure (for example, through certification systems and other documentation to check the supply chains) that the use of agricultural biomass for bioplastic packagings does not undermine the millennium goals mentioned.

The ongoing long-term conversion process towards a biogenic carbon network will only proceed without adverse environmental and social impacts if we manage to utilize residual biomass as a raw material.

9. How should the further promotion of bioplastic packagings be designed?

There are various studies that focus on the topic of utilizing biomass as a material. Three studies that can be viewed as being particularly relevant for Germany are listed below:

- Development of support instruments for the utilization of renewable raw materials as materials in Germany, 2010 [Carus et al. 2010]. This study is sponsored by Fachagentur Nachwachsende Rohstoffe (FNR).
- Analysis of the need for action by the Federal Ministry of Economics and Technology (BMWi) resulting from the EU Commission's lead market initiative (LMI) for bio-based products outside the energy sector, 2010 [Wydra et al. 2010] This study was conducted on behalf of BMWi.
- Climate protection and optimized development of renewable energy forms through cascaded utilization of biomass – potentials, developments and chances of an integrated strategy for the use of biomass as a material and an energy source [Arnold et al. 2009].

All studies mentioned show that there already is a large number of support options (see the overview taken from [Arnold et al. 2010] in Appendix II, for example) that address the issue from different angles. But these options should be integrated into an overall master plan in the future.

When it comes to the role of the Packaging Ordinance, one could take a look beyond the pure waste management aspects towards a policy of product responsibility and outline the potential role of the Packaging Ordinance as part of such a master plan. One should keep in mind that the future requirement will be to ensure a reliable and sustainable raw material supply for producing bioplastics.

As mentioned above, biomass will play a part here as a source of carbon. Another goal is to provide relief of the pressure on primary raw materials by using secondary raw materials through multiple or cascaded utilization. The plastic packaging sector is dependent on high-quality recycled materials. Other synergy potential can be utilized by combining the two aspects: material recycling of bioplastic packagings or use of bioplastics in multi-way packagings. Steering instruments that are incorporated in the Packaging Ordinance should target these aspects.

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8 Appendix I: Position statements by associations

8.1 Position statement by European Bioplastics

- The privileged status of compostable bioplastics in the German Packaging Ordinance had a signal effect beyond Germany and demonstrated the support for this innovative industry provided by the German Federal Government.

- Although the existing regulation was able to improve the competitive position of compostable packaging in some application cases, there has been no truly significant market breakthrough of compostable packaging as yet.

- The reasons are multifaceted; one of them was the unharmonized legal environment, e.g. the Biowaste Ordinance which denies bioplastics access to biowaste collection despite certification. (The current revision could remedy this.)

- But the main reason is that there no sufficient progress has been made to reduce the price difference between conventional and compostable plastics.

- European Bioplastics is also observing a change in product strategy among market participants: More and more bio-based, non-compostable packagings are introduced to the German market (Danone, Coca-Cola, Volvic). This trend could not be foreseen when the special regulation was adopted, and therefore these packagings do not benefit from this regulation.

- At the time when the special regulation was introduced, the market participants were geared towards composting and the associated disposal via biowaste collection. The picture is much more complex today, when optimized utilization conditions by product/product group are strived for. Bioplastic packagings are no longer aimed at composting alone.

- Packaging made from bio-based standard plastics (PE, PET, soon also PP) can be recycled at high quality in the established systems, together with the respective conventional plastics.

- Packagings from new bio-based materials

    - are in the medium term to be recycled as materials where their use allows it by establishing a recycling system for them. This method would be suitable for PLA yogurt pots. Reusing the plastic material (flow management) saves energy and is environmentally gentle.

    - can also make sense in organic recycling if their second use helps to collect and recycle organic waste. This applies to various applications, such as compostable carrier bags or flatware for catering.

- In general, bioplastics, whether compostable or not, can be recovered energetically because all bioplastic packagings available in the market contain (sometimes large) percentages of renewable raw materials. They only release the carbon the plants had removed from the atmosphere during combustion, so the climate is protected and crude oil is saved. Such thermal utilization is particularly suitable where there is no biowaste collection or where a respective recycling system has not been established because there only are small amounts of material (PLA) in the market.

- European Bioplastics considers the Packaging Ordinance an important building block of an overall strategy aimed at organizing the disposal of bioplastic packagings as efficiently and sustainably as possible. The industry would like to work out optimized solutions in a dialogue with all stakeholders involved.

- For the reasons mentioned (to support the use of renewable raw materials, climate protection, economical use of fossil resources, improved recycling and economies of scale), European Bioplastics is committed to keeping special regulations on bioplastics in the Packaging Ordinance beyond 2013, albeit in a modified form.

- Experience gained in other countries and established support mechanisms can provide valuable hints for the discussion to come. Some examples: Provisions on individual product categories, innovation bonus, bonus for renewable raw materials (e.g. for thermal recycling), grants for establishing recycling systems (PLA), consumer education, making biowaste collection accessible, equal treatment and promotion of recycled and bio-based material, promotion of ecologically advantageous packagings.

8.2 Position statement of Industriegemeinschaft Kunststoffverpackungen (Plastic Packaging Industry Association)

IK Industrievereinigung Kunststoffverpackungen e.V.

IK position on the UBA research project titled "Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics"

September 1, 2011

The transitional regulations for packagings made of biodegradable plastics in accordance with Article 16 of the German Packaging Ordinance will expire on 31/12/2012. They contain special facilities for biodegradable plastics in packaging applications under the conditions stipulated with respect to the implementation of product responsibility and to recycling requirements. In addition, biodegradable plastic packagings were exempt from the licencing fee, one-way beverage packagings were exempt from deposits for a limited time.

1. Do you wish to see

   ☐ a renewal of the existing special regulation

   ☒ the special regulation abolished

   ☐ a modification and adaptation of the existing regulation to account for current or foreseeable future developments?

   (Please give a brief explanation of your selection)

IK does not support a special regulation in principle, neither for biodegradable nor for bio-based plastics. If an increased use of bioplastics is to be supported, this should be done using other means such as sponsoring innovation, not a special regulation that deals with the end of the life cycle.

2. Did the existing special regulation contribute to improving the competitive position of packaging made of bioplastics in the German market?

The manufacturers or processors are divided over this. The previous special regulation is viewed as a political signal that did not change much in the market.

3. Did your products in particular benefit from the special regulation?

The manufacturers and processors think that most products did not benefit from the special regulation. It may have worked for carrier bags.

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4. Are there obstacles for establishing packagings made of bioplastics in the German packaging market? What are these?

Yes, there are. Due to the lack of a performance profile compared to conventional plastics and also due to the high price and lack of availability, packagings made of bioplastics have not yet become established in the German market.

5. The focus has been on biodegradable plastics so far. Do you see this aspect remain in the focus, or do you think there will be a shift towards bio-based plastics that are non-biodegradable?

As the IK sees it, there is a trend towards bio-based plastics, whether they are biodegradable or not.

8.3 Position statement of PlasticsEurope

Survey of opinions on the UBA research project titled "Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics"

The transitional regulations for packagings made of biodegradable plastics in accordance with Article 16 of the German Packaging Ordinance will expire on 31/12/2012. They contain special facilities for biodegradable plastics in packaging applications under the conditions stipulated with respect to the implementation of product responsibility and to recycling requirements. In addition, biodegradable plastic packagings were exempt from the licencing fee, one-way beverage packagings were exempt from deposits for a limited time.

1. Do you wish to see

☐ a renewal of the existing special regulation

☒ the special regulation abolished

☐ a modification and adaptation of the existing regulation to account for current or foreseeable future developments?

(Please give a brief explanation of your selection)

As the association of plastics producers, we do not support a special regulation in principle, neither for biodegradable nor for bio-based plastics. If an increased use of bioplastics is to be supported, this should be done using other means such as education and sponsoring innovation, not a special regulation that deals with the end of the life cycle.

Keeping a special regulation only makes sense if the provisions for compostable plastics are also changed in the Biowaste Ordinance and Fertilizer Ordinance and if the disposers (at community, federal state, or private sector levels) allow packagings that meet the criteria for industrial composting.

Unfortunately, proposals to collect these packagings in the biowaste bin are often rejected by operators of composting plants who fear quality issues, and these plastics are sorted out just like other plastics at screening devices.

Such biodegradable materials that are proven to be compostable should be approved for biological recycling in the Biowaste Ordinance and Fertilizer Ordinance. Proof of compostability should be provided by a test in accordance with EN 13432 or EN 14995 and manufacturer-independent product certification based on these standards.

The reference to certification according to EN 13432 or EN 14995 is independent of the raw material and is stipulated in the Biowaste Ordinance and Fertilizer Ordinance as a qualification criterion for approving compostable materials, including plastic products. Complete degradability and plant compatibility are ensured in this way. The stipulated exclusion of products that contain petroleum-based components in the current Biowaste Ordinance is an undue discrimination and a considerable obstacle for marketing and innovation, which includes the use of other innovative products that contain renewable raw materials. Therefore, we welcome the wording "made predominantly of renewable raw materials" contained in the current draft amendment of the Biowaste Ordinance that is being discussed in the Bundestag.

2. Did the existing special regulation contribute to improving the competitive position of packaging made of bioplastics in the German market?

The manufacturers are divided over this. The previous special regulation is viewed as a political signal that did not change much in the market. Similar reasons like the ones mentioned under reply 1 apply and have prevented a breakthrough effect in the value-added chain.

9 Appendix II: Biomass-related support instruments

Table 6: Overview of biomass-related support instruments

Source: [Arnold et al. 2009]

Instrument	Type of instrument	Political level	Support target
Energy policy			
Renewable Energies Act (EEG)	Fiscal stimulus	DE	Energetic use
Renewable Energies Heat Act (EEWärmeG)	Regulatory	DE	Energetic use
Market incentive programme to promote measures aimed at using renewable energies in the heat market (MIP)	Fiscal stimulus	DE	Energetic use
Biofuel Quota Act	Regulatory	DE	Energetic use
BMU programme: Optimization of the energetic use of biomass	Innovation, diffusion, and R&D policy	DE	Energetic and material use
Programme by Landwirtschaftliche Rentenbank (agricultural loan bank) Energy from land	Fiscal stimulus	DE	Energetic use
Basic Energy Research 2020+ programme by BMBF	Innovation, diffusion, and R&D policy	DE	Energetic and material use
Agricultural and forestry policy			
BMELV programme: Innovative multiple use of renewable energies, biorefineries	Innovation, diffusion, and R&D policy	DE	Material use
BMELV programme: Demonstration project on energetic use of renewable raw materials	Innovation, diffusion, and R&D policy	DE	Energetic use
Waste and product policy			
Ecodesign Directive	Regulatory policy tool	DE	Material use
Recycling and Waste Management Act	Regulatory policy tool	DE	Material use
Packaging Ordinance	Regulatory	DE	Material use
Waste Wood Ordinance	Regulatory	DE	Material and energetic use
Demonstration project, BMU programme	Innovation, diffusion, and R&D policy	DE	Support of material or energetic use possible
ERP Environmental and Energy Saving Programme	Fiscal stimulus	DE	Support of material or energetic use possible
Resources policy			
Material Efficiency Stimulus Programme of BMWi VerMat	Diffusion instrument	DE	Support of material or energetic use possible
Material Efficiency Stimulus Programme of MWi NeMat	Institutional	DE	Support of material or energetic use possible

10 Appendix III: Questionnaire for data collection from bioplastics manufacturers and biopackaging manufacturers

UBA Research Project

Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics

Questionnaire for Data Collection

Created by ifeu-Institut für Energie- und Umweltforschung Heidelberg GmbH

1. Explanation

The Institute for Energy and Environmental Research (Institut für Energie- und Umweltforschung; IFEU) in Heidelberg was asked by the Federal Environmental Agency of Germany to conduct the research project titled "Study of the Environmental Impacts of Packagings Made of Biodegradable Plastics".

This project is based on existing transitional regulations for packagings made of biodegradable plastics in accordance with Article 16 of the German Packaging Ordinance. These regulations will expire on December 31, 2012. The legislator will then have to decide how the topic of biodegradable packagings is to be handled in the future. It is therefore an objective of this research project to review the existing regulation and to contribute to the further development of the Packaging Ordinance.

This questionnaire is meant to determine the current and future market situation for bioplastic packagings in Germany.

The term "bioplastics" has the following meanings:

- Biodegradable plastics made of renewable raw materials, fossil raw materials, or a mixture of the two
- Non-biodegradable plastics made of renewable raw materials or mixtures of fossil and renewable raw materials

The questionnaire is divided into 4 sections:

1. The Market Situation in 2009
2. Forecast
3. Survey of Opinions
4. Disposal

Please enter the information you know as accurately as possible in the respective boxes in Sections 1-3. Section 4 deals with disposal. If you have any information about this topic, we would be grateful for your additional input.

Please specify quantities in megagram [Mg] (1 Mg = 1 metric ton).

After you have completed the questionnaire, please send it to the following address:

Institut für Energie-und Umweltforschung (IFEU)
Stichwort: UBA Biokunststoffe
Wilckensstrasse 3
69120 Heidelberg
(Email address, if required: Benedikt.kauertz@ifeu.de)

Thank you for your cooperation.

General information about the respondent

Name of the company:

Location:

Turnover of the company per annum:

Contact for questions

Name:

Phone:

Email:

2. The Market Situation in 2009

Bioplastics

Which of the types of bioplastics listed below does your company produce?
How many of them were produced in total in 2009, how many for the German market? (Please check)

	Total quantity (Mg/a)	Quantity in DE (Mg/a)	Trade name/ Type designation
☐ Starch-based plastics:	_______	_______	______________
☐ Polylactide (PLA) :	_______	_______	______________
☐ Polyhydroxyalkanoates:	_______	_______	______________
☐ Cellulose-based plastics:	_______	_______	______________
☐ Bio-polyamides:	_______	_______	______________
☐ PET made from partially or fully bio-based raw materials:	_______	_______	______________
☐ Biodegradable polyesters based on fossil raw materials:	_______	_______	______________
☐ Polyesters based on renewable raw materials:	_______	_______	______________
☐ Others:	_______	_______	______________

Blends/additives

1. Does your company produce blends/compounds of the above types of plastics?
   If yes, which are these? (Please check)

☐ No, none

☐ Yes, the following: (Mg/a)

- ☐ Thermoplastic starch + Ecoflex __________
- ☐ Thermoplastic starch + Ecoflex __________
- ☐ Cellulose-acetate + PLA __________
- ☐ ________________________________ __________
- ☐ ________________________________ __________
- ☐ ________________________________ __________
- ☐ ________________________________ __________

2. Do you use any additives in this process? (Please indicate the four most important ones in terms of quantity)

☐ No, none

☐ Yes, the following:	(Mg/a)	Quantity added [in %]
☐ ______________	______	______________
☐ ______________	______	______________
☐ ______________	______	______________
☐ ______________	______	______________

Raw materials

Which raw materials did your company use for producing bioplastics in 2009? What was the percentage of raw materials obtained from genetically modified organisms (GMOs)? (Please check)

	Total quantity (Mg/a)	Quantity in DE (Mg/a)
☐ Starch	______	______
☐ Sugar from sugar cane	______	______
☐ Sugar from sugar beets	______	______
☐ Maize starch	______	______
☐ Potato starch	______	______
☐ Wheat starch	______	______
☐ Wood	______	______
☐ Fossil raw materials	______	______
☐ Others	______	______

3. Market Forecast

1. How do you see the sales development of your bioplastic materials in the next 5 years? (Please check)
   Please specify a respective quantity in % for any increase or decrease forecast.

Packaging materials	rising	steady	dropping
☐ Starch-based plastics:	______	☐	______
☐ Polylactide (PLA) :	______	☐	______
☐ Polyhydroxyalkanoates:	______	☐	______
☐ Cellulose-based plastics:	______	☐	______
☐ Biodegradable polyesters based on fossil raw materials:	______	☐	______
☐ Polyesters based on renewable raw materials:	______	☐	______
☐ Bio-1,3-propanediol-based polymers	______	☐	______
☐ PE from bioethanol:	______	☐	______
☐ Bio-polyamides:	______	☐	______
☐ PET made from partially or fully bio-based raw materials:	______	☐	______
☐ Others:	______	☐	______

2. How do you see the sales development of packaging products made from your bioplastic materials in the next 5 years? (Please check)
   Please specify a respective quantity in % for any increase or decrease forecast.

Packaging materials	rising	steady	dropping
☐ 1. Shape-retaining products:	______	☐	______
☐ 1.1 Beverage bottles	______	☐	______
☐ 1.2 Beverage cups	______	☐	______
☐ 1.3 Yogurt pots	______	☐	______
☐ 1.4 Disposable tableware	______	☐	______
☐ 1.5 Bowls	______	☐	______
☐ 1.6 Boxes	______	☐	______
☐ 1.7 Other bottles	______	☐	______
☐ 2. Flexible film products:	______	☐	______
☐ 2.1 Carrier bags	______	☐	______
☐ 2.2 Other bags	______	☐	______
☐ 2.3 Air bubble films	______	☐	______

Packaging materials	rising	steady	dropping
☐ 2.4 Nets	________	☐	________
☐ 2.5 Other	________	☐	________
☐ 3. Foamed products	________	☐	________
☐ 3.1 Menu boxes	________	☐	________
☐ 3.2 Packaging chips	________	☐	________
☐ 3.3 Other	________	☐	________

4. Survey of Opinions

The transitional regulations for packagings made of biodegradable plastics in accordance with Article 16 of the German Packaging Ordinance will expire on 31/12/2012. They contain special facilities for biodegradable plastics in packaging applications under the conditions stipulated with respect to the implementation of product responsibility and to recycling requirements. In addition, biodegradable plastic packagings were exempt from the licencing fee, one-way beverage packagings were exempt from deposits for a limited time.

2. Do you wish to see
   - ☐ a renewal of the existing special regulation
   - ☐ the special regulation abolished
   - ☐ a modification and adaptation of the existing regulation to account for current or foreseeable future developments

   ? (Please give a brief explanation of your selection)

3. Did the existing special regulation contribute to improving the competitive position of packaging made of bioplastics in the German market?

4. Did your products in particular benefit from the special regulation?

5. Are there obstacles for establishing packagings made of bioplastics in the German packaging market? What are these?

6. The focus has been on biodegradable plastics so far. Do you see this aspect remain in the focus, or do you think there will be a shift towards bio-based plastics that are non-biodegradable?

5. Disposal of Packagings Made of Bioplastics in Germany

1. To what extent did packagings from bioplastics in 2009 go from domestic waste to material recycling by composting or fermentation?
   (Please check)

	(Mg/a) or alternatively in %
☐ "Industrial" composting plants:	____________
☐ Home composting:	____________
☐ Fermentation:	____________

2. What quantities and packaging types entered composting or fermentation through special activities in 2009? (Please check)

	Quantity
☐ Events:	____________
☐ Other (please specify briefly):	____________
________________________	____________
________________________	____________

3.
   a) What quantities and packaging types were disposed into the yellow bag in 2009?
      ____________(Mg/a) or alternatively in percent
   b) What quantities and types of packaging were mechanically recycled in 2009?
      ____________(Mg/a) or alternatively in percent
   c) What quantities and types of packaging thereof were subjected to another type of material recycling in 2009?
      ____________(Mg/a) or alternatively in percent
   d) What quantities and types of packaging thereof were subjected to thermal recycling in 2009?
      ____________(Mg/a) or alternatively in percent

4. What quantities of bioplastics were disposed of by thermal recycling via the residual waste route in 2009?

   ____________(Mg/a) or alternatively in percent

5. What developments do you anticipate in the next 5 years with respect to the disposal of packagings made of bioplastics in Germany (please explain).

11 Appendix IV: Scenario assumptions according to the BMFZ study

Table 1: Assumptions in each scenario for the global considerations (source: Universität Hohenheim, vTI, DBFZ)

Business as usual (BAU)	• Land use changes such as forest clearing and ploughing up of grassland; • 10% yield increase through technological progress, e.g. for short-rotation coppice plantations and forestry plantations in 15 years; • Cultivation shares of crops remain the same (as found in base, primarily focused on food production); • Linear proportional growth of ecological farming as in the past 18 years.
Bioenergy (B)	• Land use changes such as forest clearing and ploughing up of grassland; • Change of the cultivation mix towards crops with the highest yield (energy crop rotation) • 1/3 wood-like substrates (short-rotation coppice plantations in the moderate climates, plantations in tropic climates), the crops with the highest yields in the country group to the rotation limits for the location • Clear increase in prices for agricultural raw materials, strong incentive to achieve a 50% yield increase compared to the BAU scenario for all crops.
Bioenergy with increased environmental and nature conservation restrictions (B&U)	• Assumptions of cultivation mix and yield increases as in (B) • Strict ban on clearing primary forest and ploughing up of grassland; • 10% of the forests in the boreal and moderate zones taken out of use and protected for species and biotope conservation; • 50% of the area in tropical primary forests protected and no longer used; • Extension of nature conservation areas by providing another 2% of the farmland for reallocation.
Pure area scenario: Business as usual with increased environmental and nature conservation restrictions plus diet change (BAU&U+E)	• Reduced caloric expenditure of overnourished people by up to 30% • Change in demand in favour of products of ecological farming • Disproportionate expansion of ecological farming (doubling within 10 years) • Reduced yield increases compared to the BAU scenario: 5% by 2010, 10% by 2015, 15% by 2020, and 45% by 2050.

12 Appendix V: Tabular overview of the documents searched

Explanations: The file contains two table sheets:

<Literatur Ökobewertung> Literature overview

<Dokumentation Recherche> Notes on the Internet search