Land-Based Solutions for Plastics in the Sea

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D5.8 – Recommendations and Guidelines Concerning Production, Use and Disposal of Biodegradable Polymers

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Executive summary:	Based on biodegradation tests and two life-cycle assessment (LCA) case studies performed within the LABPLAS project, we summarize our conclusions and recommendations concerning the production, use and disposal of biodegradable polymers in this document. In the two LCA case studies, the production phase of biodegradable polymers was identified as one of the major drivers affecting the environmental impact due to high energy and material consumption. The study further showed that increasing the percentage of biogenic carbon in the raw materials can reduce environmental impacts significantly. Therefore, **the acceptance, promotion, and further development of existing and new sustainable production processes are crucial to improving the environmental performance of biodegradable plastics.** Furthermore, considering specific end-of-life scenarios, it was shown that biodegradable plastics can have a superior environmental performance compared to non-biodegradable plastics. Therefore, **biodegradable plastics could be beneficial in specific applications**

	with intended usage in the open environment, where collection of the plastic is not feasible and/or recycling is not possible. Other advantageous applications could be where they increase the collection rate of organic waste or reduce the contamination of compost with persistent microplastics. Biodegradable plastic materials are designed to biodegrade after their use phase in a specific end-of-life, which can avoid the accumulation of persistent microplastics. Even though the biodegradation test results from Task 5.3 show that a certified compostable polymer might biodegrade in different unintended end-of-life scenarios, **we recommend that biodegradable plastics shall not under any circumstances be promoted as a solution for plastic littering or justify/encourage the intentional mismanagement of plastic waste.** The solution to plastic littering should be to fight at the source by changing consumer behaviour concerning intentional disposal and by establishing functioning waste management systems globally.

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ABBREVIATIONS AND ACRONYMS

Abbreviation / Acronym	Description
BMB	Bio Mass Balance
ISO	International Organization for Standardization
LCA	Life-Cycle Assessment
LCIA	Life-Cycle Impact Assessment
LDPE	Low-density polyethylene
PBAT	Polybutylene adipate-*co*-terephthalate
PBSeT	Polybutylene sebacate-*co*-terephthalate
PHB	Polyhydroxybutyrate
PLA	Polylactic acid
RP	Reporting Period
T	Task
WP	Work Package

1 INTRODUCTION

Biodegradable plastic materials are designed to biodegrade after their use phase in a specific end of life. The biodegradation process is facilitated by microorganisms which are naturally present in the respective environment. As a result of biodegradation under aerobic conditions, for example, the polymer is converted into biomass, carbon dioxide, and water. Importantly, the sole fragmentation of conventional plastics into smaller particles, such as microplastics, is not considered biodegradation, but per definition, biodegradation requires the conversion of the plastic material into the above-mentioned products. Therefore, the accumulation of persistent microplastics through the fragmentation of conventional plastics can be avoided using biodegradable plastics which can be beneficial for selected applications, in which, for example, recycling is not possible or feasible.

This document is resulting from Task (T) 5.6 in the LABPLAS project. Herein, we analyze the most remarkable results and conclusions from T5.3 and T5.5 as part of work package (WP) 5 - *Biopolymers*. Based on this analysis, **we provide recommendations concerning the production, use, and disposal of biodegradable polymers to allow for informed decision-making on the industry and regulatory levels**. In T5.3, the biodegradation and disintegration of a compostable polymer in different environments were assessed according to standard and developmental methods. In T5.5, two life-cycle assessment (LCA) case studies with garbage bags and mulch films were conducted to compare the environmental performance of conventional (fossil-based and non-biodegradable) plastics with biodegradable alternatives. Notably, the results and main findings from T5.4, in which the toxicity of decomposition intermediates from biodegradable plastics was intended to be analyzed, were not included in this analysis because most of the experimental protocols used did not allow a comprehensive assessment of the toxicity and they require further optimization. However, published toxicity data were included in the LCA from T5.5.

The following two sections summarize the main findings from T5.3 and T5.5 on a superordinate level without presenting excessive details. Further information including method descriptions and detailed results can be found in the respective Deliverables (D) 5.1, D5.2, D5.3, D5.6, and D5.7.

2 MAJOR FINDINGS FROM T5.3 - BIODEGRADATION AND DISINTEGRATION OF A COMPOSTABLE POLYMER IN DIFFERENT ENVIRONMENTS

Even though biodegradable materials are designed only for disposal in a defined end-of-life environment, unintended leaking might happen in locations where waste management systems are not well established or by irresponsible behaviour of individuals. Therefore, in T5.3, the biodegradability assessment was not only limited to the intended end-of-life environment but also various unintended end-of-life scenarios were included, such as freshwater, soil, and marine. Certified compostable polybutylene sebacate-*co*-therephthalate (PBSeT) was used as a model biodegradable polymer. All biodegradation test methods were performed according to or modified from internationally accepted and validated standards, for example, ISO 19679 and ISO 17556, which use respirometry as test principle. In addition, disintegration tests under marine field conditions were conducted based on a modified ISO 22766 protocol to complement the results obtained from the laboratory biodegradation experiments. The endpoints tracked were weight loss and area loss of the plastic films recovered at specific time points.

The results indicated that PBSeT was biodegraded under laboratory conditions in all environmental compartments tested with some variations in the kinetics and the extent of biodegradation, as to be expected due to the different inocula and conditions investigated. Furthermore, complete disintegration of the PBSeT plastic film under marine field conditions was observed.

3 Major Findings from T5.5 – Comparative Life-Cycle Assessment of Biodegradable Vs. Non-Biodegradable Plastic Products

Two LCA case studies were conducted within a European context (EU with 28 member countries) to compare the environmental performance of conventional (fossil-based and non-biodegradable) plastics with biodegradable alternatives. The cradle-to-grave approach was applied which covers the entire product life cycle, from raw material acquisition to product manufacturing, distribution, use phase, and final disposal of the product. The studies focused on mulch films used for tomato cultivation and garbage bags used for the collection of organic kitchen waste. A range of different environmental impact categories were assessed in the study, including climate change potential, air pollution, aquatic eutrophication, and human and freshwater toxicity, among others. Furthermore, the LCA study included the often-overlooked consequences of microplastic leakage during end-of-life phases. To do so, both the biodegradability and toxicity effects of plastic have been considered to calculate their impacts on biodiversity.

3.1 Case Study 1 – Mulch Films

In the mulch film case study, different disposal options were evaluated: For biodegradable mulch films made from polybutylene adipate-*co*-terephthalate (PBAT) and polylactic acid (PLA) and complying with EN17033:2019, biodegradation in soil was chosen as (intended) end-of-life (Figure 1). For non-biodegradable mulch films made from low-density polyethylene (LDPE), open burning and littering into the soil were included as relevant end-of-life scenarios, each accounting for 50% in the base case. Additionally, mechanical recycling, incineration and landfilling were considered individually as alternative end-of-life scenarios to assess their effect on the overall environmental performance. Furthermore, in terms of the raw materials used, it was assumed that PBAT was obtained from fossil-based sources and PLA contained 9% biogenic carbon derived from starch. For LDPE, it was assumed that the raw material used for polymer production was entirely fossil-based.

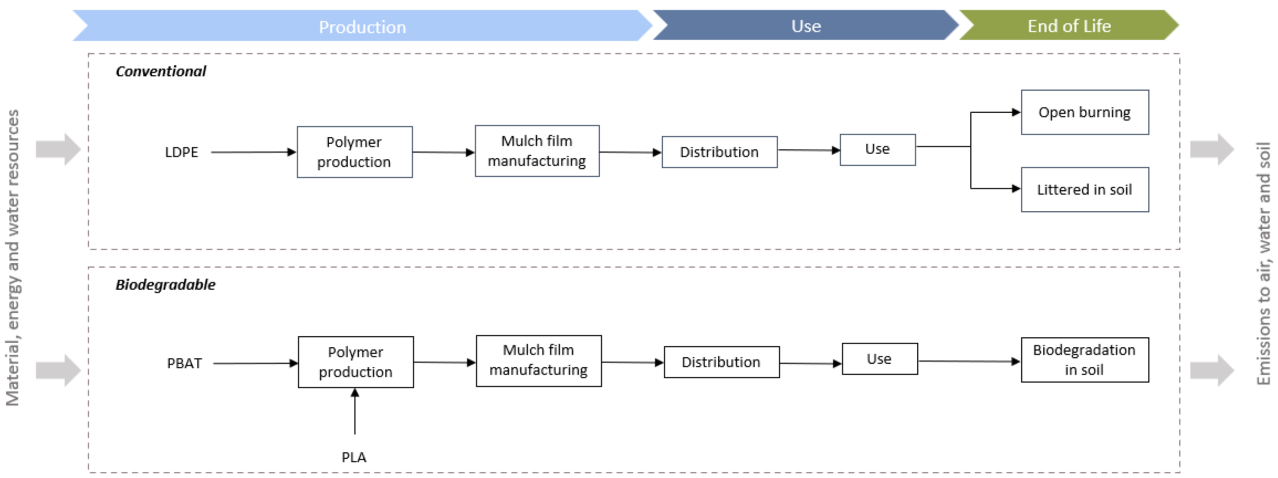

Figure 1. System boundaries of conventional and biodegradable mulch film included in the LCA case study performed in Task 5.5 of the LABPLAS project.

The most relevant impact categories for the conventional mulch film were climate change (35%), fossil resource use (34%), and particulate matter (10%; potential incidence of human disease due to particulate matter emissions). The major drivers for these impact categories are the consumption of fossil resources and energy in the production phase of LDPE granules. The most relevant impact categories for the biodegradable mulch film were climate change (36%), fossil resource use (25%), and water use (11%). The environmental impact of the biodegradable mulch film was primarily attributed to the energy and material consumption during the polymer production phase of PBAT and the film manufacturing stage.

Overall, the conventional mulch film showed a higher environmental impact compared to the biodegradable mulch film in numerous impact categories such as non-cancer and human cancer toxicity, particulate matter, photochemical ozone formation, freshwater ecotoxicity, and fossil resource use. The higher impact in the toxicity-related categories was explained by toxicity emissions generated during the incineration process. The biodegradable mulch film showed better environmental performance in all categories except for climate change and land use when compared to the base case (50% open burning, 50% littering of conventional mulch film), as well as to the individual landfilling and incineration scenarios. When compared to recycling, without considering the credits associated with the avoidance of producing new LDPE polymer, biodegradation appears to be a better option in all impact categories. Based on this LCA, landfilling, open burning and incineration present significant environmental burdens across several impact categories, and although the recycling process has credits for avoiding the production of new material, it is highly energy-intensive and faces several barriers during collection such as plastic fragmentation and the collection of topsoil. Furthermore, biodegradable materials can ultimately be mineralized and converted into carbon dioxide, whereas LDPE is not biodegradable, resulting in the accumulation of persistent microplastics in the soil**. Therefore, biodegradation emerges as the preferable disposal option from an environmentally friendly perspective.**

Further, one option to decrease the environmental impacts associated with the production of the raw materials is to apply the certified biomass balance approach where 100% of fossil feedstocks required for this product have been replaced by renewable feedstocks from waste and residual biomass at the beginning of the value chain (https://www.basf.com/massbalance). It was shown that the application of the biomass balance approach for the production of PBAT leads to a significant reduction in numerous impact categories, such as particulate matter (-69%), fossil resource use (-56%), photochemical ozone formation (-39%), and climate change (-37%). **Therefore, by reducing dependence on non-renewable resources and utilizing biodegradable materials this alternative presents a sustainable option to conventional mulch films.**

3.2 Case Study 2 – Garbage Bags

In the garbage bag case study, garbage bags for the collection of 1.4 kg of kitchen waste were evaluated. The garbage bags included were made from three different materials: LDPE, PBAT, and kraft paper. Industrial composting was considered as the only end-of-life scenario (Figure 2). Therefore, biodegradability and microplastic formation were a key point for the study.

Based on the LCA, conventional plastic bags demonstrate better environmental performance overall, coinciding with the fact that the weight of plastic bags plays an important role in their environmental impact, with the conventional plastic bag being the lightest. Additionally, it is important to note that conventional plastics are being used for composting in this study, which is not their typical use. **Current LCIA (Life-Cycle Impact Assessment) methodologies are not capable of fully accounting for the effects of non-biodegradability over the product's lifecycle.** Therefore, to fully understand these results, it is crucial to consider the impacts of microplastics. The generation of microplastics depends on fragmentation, with a higher rate leading to a greater impact. Conventional plastic bags, made from LDPE, tend to break down into smaller fragments over time, resulting in the accumulation of persistent microplastics in the environment.

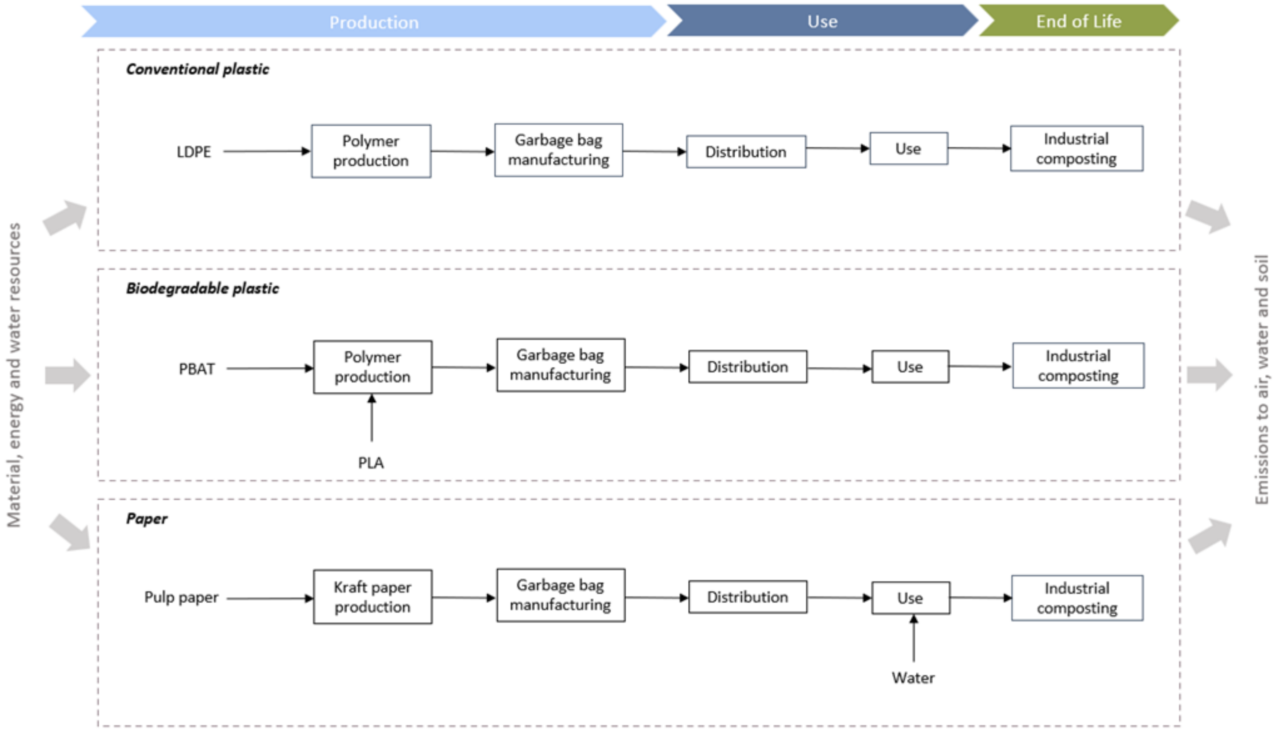

Figure 2. System boundaries of conventional, biodegradable and paper waste bags included in the LCA case study performed in Task 5.5 of the LABPLAS project.

For the conventional plastic bag, the composting process is the main source of impact across all impact categories, ranging from 59% to nearly 100% for water use and freshwater ecotoxicity. **The use of non-biodegradable materials for composting has a significant impact on terrestrial ecosystems since the accumulation of persistent microplastics increases over time.** The second largest contribution to multiple impact categories derives from the production of LDPE granules and the manufacturing process of the bag due to the consumption of ethylene and electricity.

Likewise, for the biodegradable bag, the composting process is the main contributor in most of the impact categories, notably in freshwater ecotoxicity (99%), terrestrial eutrophication (98%) and acidification (95%), caused by chemicals emitted during the process as well as the electricity and fuel consumption. Similarly to the biodegradable mulch film study, high-impact values are attributed to the PBAT manufacturing phase. Replacing fossil feedstock for PBAT with renewable feedstocks from waste and residual biomass at the beginning of the value chain via a biomass balance approach, environmental impacts can be reduced significantly.

For the paper bag, the composting process emerges as the main contributor in most of the impact categories due to the emission of chemicals during degradation and the electricity and fuel consumption involved in the process. Manufacturing of the bag also has a significant contribution to various impact categories, such as freshwater eutrophication (73%), ionizing radiation (43%) and ozone depletion (38%), due to the consumption of electricity and fuels, as well as all emissions at the mill, both from the cooking and recovering processes and combustion of fuels at different points at the plant.

It was further evaluated how the environmental impacts of disposing of 1.4 kg of kitchen waste in biodegradable plastic bags are influenced by various end-of-life scenarios, including industrial composting (base case), home composting, anaerobic digestion, landfill and incineration. In this evaluation, home composting showed the lowest impacts in almost all categories, due to reduced electricity and fuel consumption. However, home composting faces challenges such as odour, pests and incomplete decomposition. **The most environmentally friendly options identified were composting and anaerobic digestion.** Although not explicitly considered in the analysis, these options also offer the added benefit of avoiding the consumption of new resources. Composting reduces the need for synthetic fertilizers, while anaerobic digestion decreases the reliance on natural gas by producing biogas. In conclusion, **when considering end-of-life scenarios, biodegradable alternatives showed higher environmental benefits compared to non-biodegradable plastics.**

4 Conclusions and Recommendations

4.1 Recommendations regarding the production of biodegradable polymers

In the two LCA case studies performed in the LABPLAS project, the production phase of biodegradable polymers was identified as one of the major drivers affecting the environmental impact across multiple categories. This impact was primarily attributed to high energy and material consumption. The study further showed that increasing the percentage of biogenic carbon in the raw materials can reduce environmental impacts significantly. Therefore, **the use and promotion of existing sustainable production processes, such as the certified BMB approach, as well as the development of new sustainable production processes are crucial to further improve the environmental performance of biodegradable plastics.**

4.2 Recommendations regarding the use of biodegradable polymers

Results from the two LCA case studies show that biodegradable mulch films and garbage bags show better environmental performance compared to non-biodegradable plastics when considering specific end-of-life scenarios. Therefore, **biodegradable plastics could be beneficial in specific applications with intended usage in the open environment, where collection of the plastic is difficult and/or recycling it is not possible,** for example in certified soil biodegradable mulch film applications. Other examples where the replacement of conventional by certified biodegradable plastics could be beneficial are small parts of fishing gear and extensive aquaculture materials which could be easily lost in the sea, for example, dolly ropes, buoys, and mussel farming sticks. **Further advantageous applications could be where they increase the collection rate of organic waste or reduce the contamination of compost with persistent microplastics**, for example, certified compostable garbage bags for the collection of bio waste. Importantly, the biodegradability of a plastic product should be certified based on validated, internationally accepted, and standardized biodegradation test methods and certification schemes to ensure sufficient biodegradation in the receiving environment.

4.3 Recommendations regarding the disposal of biodegradable polymers

The results obtained from the biodegradation assessment within the LABPLAS project indicate that in case of accidental and/or unintended leaking, a compostable material is also biodegradable in other unintended end-of-life habitats. Therefore, the use of biodegradable plastics could potentially support reducing the accumulation of persistent microplastics released from non-biodegradable plastics over time. However, **we recommend that biodegradable plastics shall not under any circumstances be promoted as a solution for plastic littering or justify/encourage the intentional mismanagement of plastic waste.** The solution to plastic littering should be to fight at the source by changing consumer behaviour concerning intentional disposal and by establishing functioning waste management systems globally.