UNIVERSIDADE DO ALGARVE

UNIVERSITAT DE BARCELONA

ALMA MATER STUDIORUM UNIVERSITÀ DI BOLOGNA

ChIR Chemical Innovation & Regulation

BIODEGRADABLE PLASTICS AND THE ENVIRONMENT: A SUSTAINABLE SOLUTION OR A NEW PROBLEM?

EO2 (Environmental Risk of Plastic Materials)

ERASMUS+

APRIL 30, 2023

SUBMITTED BY

Moses Kolade David

Table of Contents

List of Figures

Abstract

This minireview examines the potential of biodegradable plastics to replace traditional plastics and reduce environmental impacts, but it also raises concerns about the viability of biodegradable plastics in real-world scenarios and the need for better waste management practices. The article presents a review of essential concepts such as bioplastics, biodegradability, and bio-based materials, and discusses the efforts of various governments and regulatory entities to promote biodegradable solutions.

Introduction

Plastics are utilized practically everywhere, such as in everyday domestic packaging, bottles, smartphones, printing devices, and so on. It is also used in a variety of production industries, including pharmaceuticals, chemical manufacturing, aviation and autos. They are useful as synthetic polymers because their structure may be chemically altered to create increased molecular weight, low reactivity, and long-lasting compounds. Plastics are vital materials because they are long-lasting and cost-effective for everyone (Ibrahim et al., 2017; Liu et al., 2023). As a result of the widespread usage of disposable masks and gloves since the COVID-19 epidemic, as well as the growing use and manufacturing of plastics, waste materials made of plastic is virtually everywhere, from agriculture to residences, mountains to marine environments, the coastline to waste disposal facilities (Guan et al., 2023; Tanunchai et al., 2023).

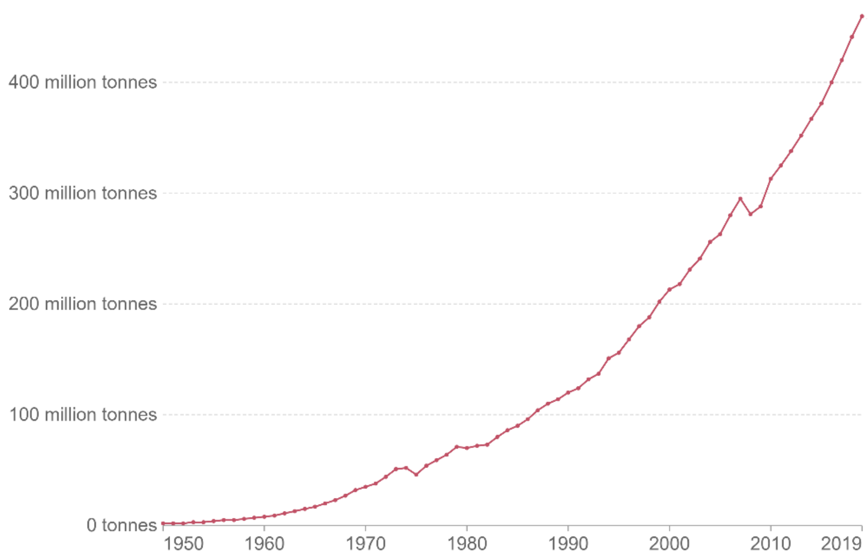

Figure 1. Global plastics production; Plastic production refers to the annual production of polymer resin and fibers (Ritchie & Roser, 2022)

Over 250,000 tons of plastic were projected to be floating around in the oceans in 2014. Under the current plastic manufacturing trend and without reforms in the waste disposal system, it is anticipated that 90 Mt/year of plastics will be entering the marine environment by 2030 (Choe et al., 2021). The global share of plastics waste mismanagement by continent is summarized in figure 2. Non-biodegradable polymers such as polyethylene (PE), polypropylene, (PP) and polyvinyl chloride (PVC) contribute significantly to plastic pollution and accumulate over time (Tanunchai et al., 2023). People are becoming more conscious of the adverse environmental impacts of petrochemical-derived plastic materials. Many studies have been undertaken to develop ecologically friendly alternatives to plastics in order to manage plastic waste on Earth (Ibrahim et al., 2017).

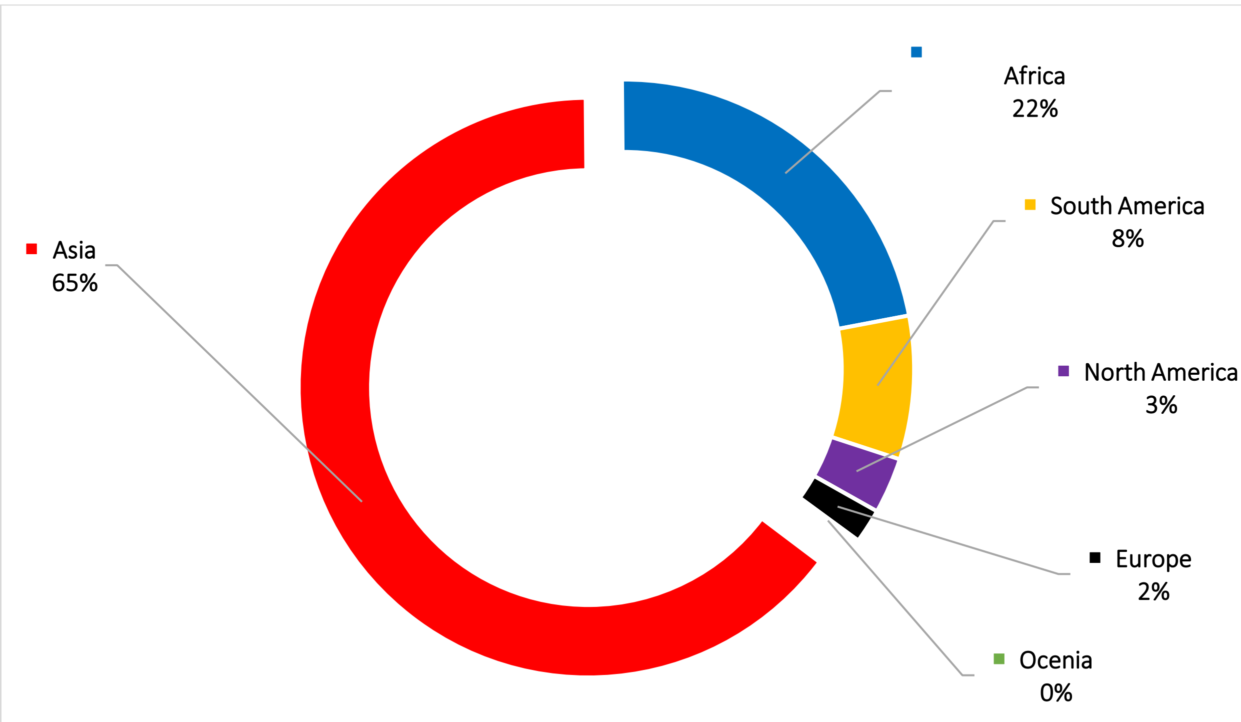

Figure 2. Share of global mismanaged plastic waste based on data adapted from (Ritchie & Roser, 2022); Mismanaged plastic waste is plastic that is either littered or inadequately disposed. This does not include waste that is exported overseas, where it may be mismanaged.

Biodegradable plastics (BDPs) have been proposed as long-term alternatives to traditional plastics. In theory, microorganisms can convert BDPs completely or partially into carbon dioxide, methane, water, biomass, humic matter, and a variety of other natural chemicals (Ibrahim et al., 2017; Mo et al., 2023) that may be easily removed with minimal environmental impact. BDPs are classified as natural or synthetic polymers based on their source components.

Natural polymers are generated from renewable resources such as plants and other biomass, whereas synthetic polymers are made from petroleum-based components (Mo et al., 2023).

Moreover, different legislations have launched initiatives to stimulate bio-based plastics (BBPs) research and development. Both governmental and regulatory entities in North America and Europe have made efforts in this direction. Malaysian and German governments have expressed strong interest in biodegradable plastics research (Moshood et al., 2022). The European Union (EU) has recognized the significance of conservation of natural resources as a means to mitigate worldwide reliance on nonrenewable resources, combat climate change, and boost economic competitiveness by means of its Bioeconomy Strategy. By developing new approaches, the Bioeconomy Strategy promotes the Green Deal, sustainable development, and the transition to a circular economy. The advancement and implementation of biobased and biodegradable solutions is emphasized in the bioeconomy initiative (Fletcher et al., 2021).

BDPs undoubtedly have a difficult challenge ahead of them. these products must pass through the whole value chain with minimal environmental impact, but after disposal in a controlled setting, they are expected to entirely assimilate as nutrients for soil microorganisms, thus ensuring the safe return of carbon to the ecosystem (Ghosh & Jones, 2021). In the midst of this issue, one fundamental concern remains: can BDPs achieve its aim if it escapes into ecosystems or is disposed of in an unsuitable approach such as in a landfill where greenhouse gas emissions are not controlled? These inquiries prompted us to scour the academic, trade, and policy literature for insights into the long-term viability of BDP adoption.

Understanding bioplastics and biodegradability – key concepts

A bioplastic is a type of plastic that is manufactured in part or entirely from polymers generated from plant-based materials like sugar cane, potato starch, or the cellulose found in trees, straw, and cotton. The term degradation refers to the process by which a polymer breaks down into smaller fragments as a result of abiotic causes such as UV radiation, oxygen attack, and biological attack. PE is the most prevalent degradable plastic. Biodegradation, on the other hand, is a biological process in which a polymer is broken down into smaller particles and turned into methane, water, and carbon dioxide with the help of microbial activity. The mode of biodegradation of polymers is determined by the thickness and composition of the substance. The keyword bio-based refers to both biodegradable plastics and those that are bio-based, which denotes that they were produced in some way from natural resources or biomass. They are either biodegradable or recyclable (Ibrahim et al., 2017). Therefore it is correct to say that bioplastics are biobased, biodegradable or both as summarized in figure 3. Furthermore, Compostable plastics are polymers that can decompose biologically in a compost site, releasing carbon dioxide, water, inorganic chemicals, and biomass without releasing hazardous substances into the environment. Compostable materials can also breakdown through the enzyme process. Polylactic acids (PLA), for instance, is excellent for both methods of totally disintegrating.

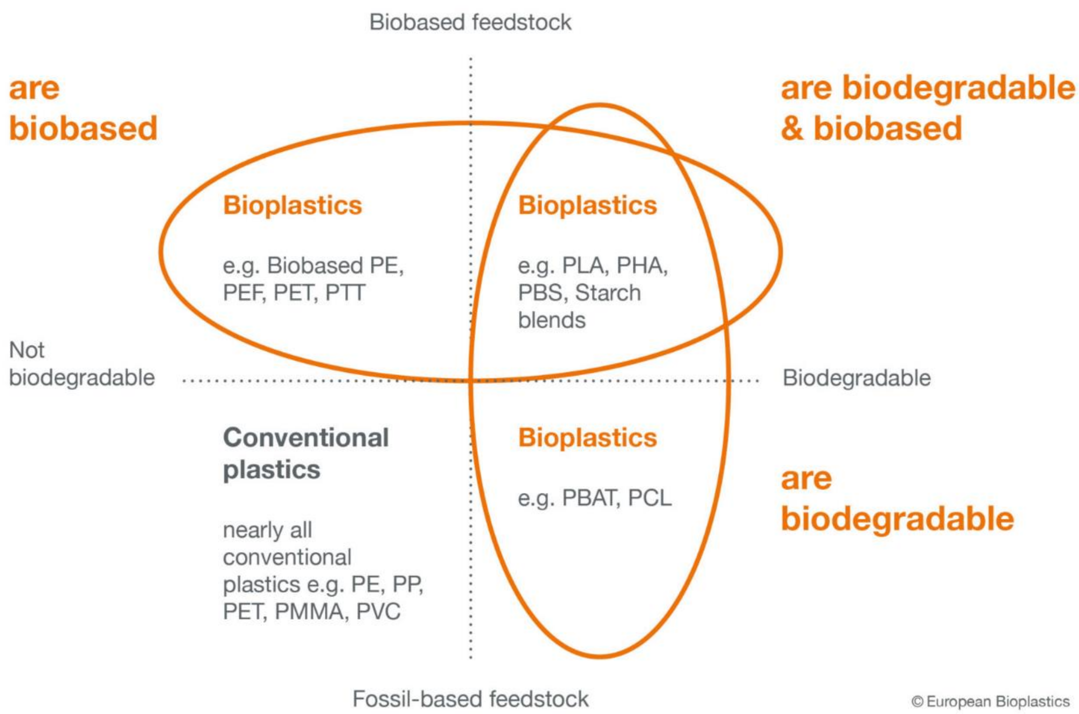

Figure 3. Material coordinate system for bioplastics (European Bioplastics, 2022)

Biodegradation mechanism

Microorganisms break down polymers into smaller molecules and eventually convert them into end products during the biodegradation process. Biodegradable plastics breakdown in four phases, beginning with the production of microbial biofilms on the surface of the material, which are then broken down into smaller fragments by decomposers or abiotic forces. Enzymes ejected from the biofilm then depolymerize the polymers into smaller units, which are ingested metabolically to form new biomass and energy. These intermediates are eventually metabolized into end products including carbon dioxide, methane, water, and mineral salts. The physicochemical structure of the materials, ambient conditions, and the microbial populations involved are all factors that influence biodegradation. Biodegradable plastics are decomposed synergistically by biotic factors such as bacteria, fungi, archaea, and algae, as well as abiotic elements such as temperature, sunshine, mechanical impact, oxygen, humidity, and acidity. Higher temperatures and humidity increase the pace of deterioration, and the presence of oxygen influences the type of decomposer and reaction. Aerobic organisms employ polymers as carbon and energy sources, whereas anaerobic organisms produce biogas, primarily methane (Choe et al., 2021; Liu et al., 2023).

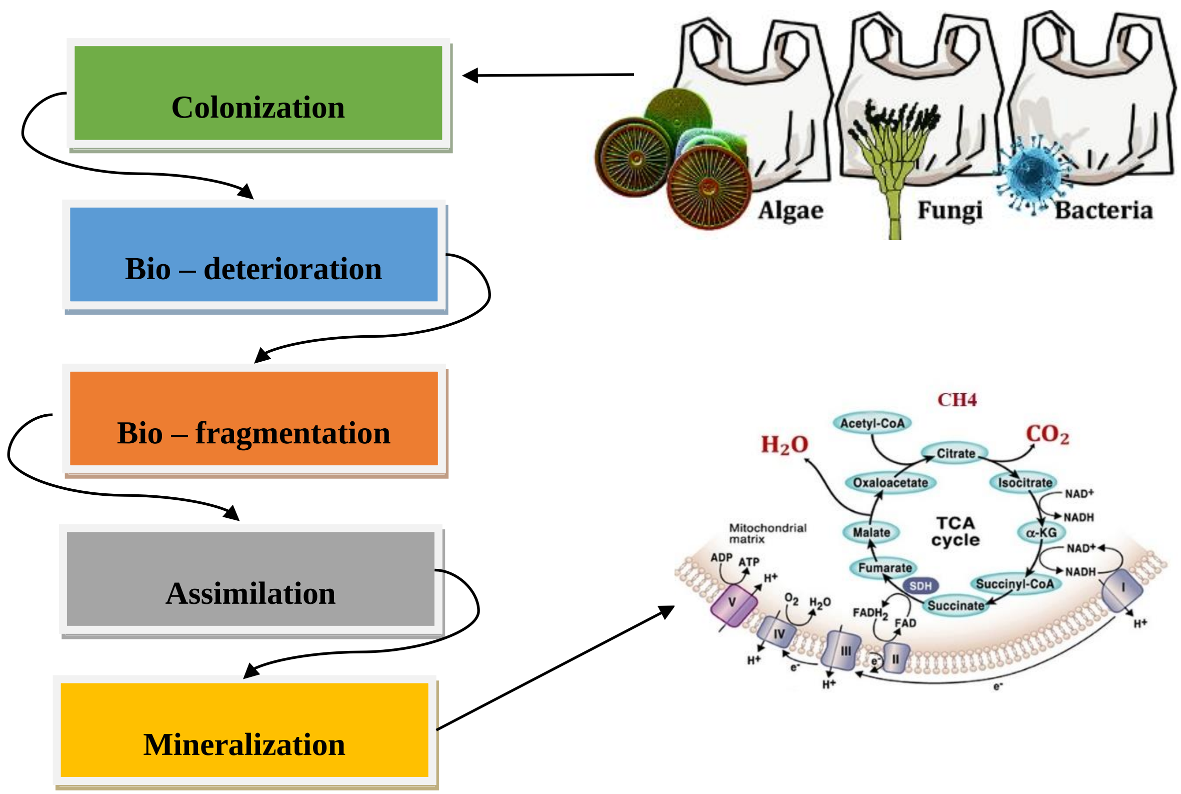

Figure 4. Biodegradation of plastic polymers (Liu et al., 2023)

Current status; market and regulations

Commercial biodegradable polymers are gaining popularity as an eco-friendly alternative to standard plastics. However, with so many different types of biodegradable plastics on the market, determining which ones are truly sustainable can be difficult. This is where certification comes into play. Certification establishes the legitimacy of sustainability claims and converts complex information into easily accessible signals across the value chain for biodegradable plastics. Because the composition and end-of-life degradation profile of each product can differ depending on factors such as thickness, size, and minor constituents, each product requires its own certification. The certification process consists of three steps: brand owners identify the brand to certify and which certification to achieve based on client needs, a third-party testing laboratory performs the required tests following guidelines from organizations like the International Organization for Standardization (ISO), American Society for Testing and Materials (ASTM), and the European Committee for Standardization (CEN), and the certifying body examines the data and makes the certification decision (Ghosh & Jones, 2021).

According to Ghosh & Jones, Aliphatic polyesters and copolyesters like poly(lactic acid) (PLA), polybutylene succinate adipate (PBSA), polycaprolactone (PCL), polyglycolic acid (PGA), and aliphatic aromatic polyesters like polybutylene adipate terephthalate (PBAT) dominate the biodegradable polymer market, as do carbohydrates like cellulose, cellulose acetate, starch, and starch blends. In 2017, the global use of biodegradable polymers was 335,000 tons, with Western Europe accounting for 52% of total consumption, followed by Asia and Oceania (25%), and the United States (22%). Foodware, plates, cutlery, bags, and kitchen trash bags are among the end-use markets for biodegradable polymers. Agriculture, horticulture, paper coatings, textiles, medical devices, oil and gas processes, and additive manufacturing are all potential markets for biodegradable polymers.

Concerns from academic literature

Alternative polymers, such as biodegradable/bio-based plastics, have gained popularity in the previous decade. Concerns have been raised, however, about the manufacture and sourcing of feedstocks for these materials. The majority of BBPs is derived from agricultural crop-based feedstocks, which may compete for arable land, fresh water, and food production, thus affecting SDG-2 and SDG-6 goals. Furthermore, the use of sustainable and ethical feedstocks may result in limited availability and high prices, limiting the bioeconomy's growth. There are also technical performance and mechanical property concerns with the usage of BBPs/BDPs, such as reduced resistance to oxygen, water, vapor, microorganisms, light, and high humidity, which is especially problematic for high-risk applications like food packaging (Fletcher et al., 2021). To address these complicated difficulties and promote the use of BBP/BDP products, it is critical to address social sustainability issues across a wide range of stakeholder groups, including employees and customers, by considering both health and safety concerns and social acceptability concerns. This necessitates the development of successful public policy. Furthermore, it is critical to manage consumer expectations that BBPs/BDPs will perform at least as well as traditional plastics, as well as to consider the impact on other SDG goals.

Concerns from non – academic literature

Non-academic literature, such as news articles, industry journals, and blogs, has significant impact on how consumers view the safety and efficacy of bio-based and biodegradable plastics. Consumer misunderstanding about the wording used to advertise these products has been examined in various sources. Terms like biodegradable, compostable, and bio-based can be confusing and possibly deceptive. Furthermore, consumers lack knowledge about these products, making it difficult for them to make informed sustainable decisions (Fletcher et al., 2021).

Another recurrent topic, according to the authors, is the authenticity of the environmental credentials connected with these products, particularly in terms of end-of-life management. Lack of adequate waste collection and management methods can prevent these conditions from being realized, resulting in inefficient end-of-life management. Furthermore, there are risks and unintended consequences associated with substituting bio-based and biodegradable plastics for petroleum-based products used in food contact materials. Concerns include the possibility of allergens and other chemicals affecting food safety and consumer protection, as well as a lack of study on the human health effects of substituting these materials for petroleum-based products.

Reflections

As community awareness of environmental issues improves, investing in the production of biodegradable plastics can provide a competitive edge. Bio-plastics have various advantages, including the fact that they are 100% biodegradable, created from renewable materials, and may be recycled, reused, composted, or burned without producing toxic byproducts. These benefits make bio-plastics an excellent alternative to traditional plastic products. Despite the fact that bioplastics seem to be ecologically benign and biodegradable, progress toward sustainability is slow due to technological challenges regarding manufacturing and field application. There is also concern that rivalry for feedstock with the bioenergy industry would limit food supplies and increase basic grain costs for future generations. Biodegradable polymers, on the other hand, have the potential to increase revenue and job possibilities in the agricultural and chemical industries. Because biodegradable plastics are not widely used in the plastic market, consumers are inadequately educated on how to dispose of them, and there is little incentive to ensure proper disposal. Adopting biodegradable plastics without considering the entire product lifecycle design, on the other hand, would be ineffective in achieving sustainability.

Conclusion

To summarize, the shift to biodegradable plastics is a positive step toward sustainable growth. However, due to technological challenges and concerns about feedstock availability, progress toward sustainability is slow. Furthermore, the use of biodegradable plastics should be done with the entire product lifecycle in mind. To avoid waste, it is critical to educate customers on how to properly dispose of biodegradable plastics. As the need for biodegradable plastics grows, more research and development is required to address emerging grey areas in this filed like how can we accelerate progress towards sustainable biodegradable plastics while ensuring food supplies and limiting costs for future generations? What measures can be taken to improve consumer education on the proper disposal of biodegradable plastics?

References

Choe, S., Kim, Y., Won, Y., & Myung, J. (2021). Bridging Three Gaps in Biodegradable Plastics: Misconceptions and Truths About Biodegradation. *Frontiers in Chemistry*, *9*. https://doi.org/10.3389/fchem.2021.671750

European Bioplastics. (2022). *Bioplastic materials*. https://www.european-bioplastics.org/bioplastics/materials/

Fletcher, C. A., Niemenoja, K., Hunt, R., Adams, J., Dempsey, A., & Banks, C. E. (2021). Addressing Stakeholder Concerns Regarding the Effective Use of Bio-Based and Biodegradable Plastics. *Resources*, *10*(10), 95. https://doi.org/10.3390/resources10100095

Ghosh, K., & Jones, B. H. (2021). Roadmap to Biodegradable Plastics—Current State and Research Needs. *ACS Sustainable Chemistry & Engineering*, *9*(18), 6170–6187. https://doi.org/10.1021/acssuschemeng.1c00801

Guan, M., Zhao, S., Shi, J., Jin, H., & Wei, W. (2023). Experimental study on the gasification characteristics of polyethylene terephthalate (PET) microplastics in supercritical H2O/CO2 environment. *Journal of Cleaner Production*, *385*, 135661. https://doi.org/10.1016/j.jclepro.2022.135661

Ibrahim, M. S., Jafar, A. J., Abubakar, S. A. S., Saleh, Y., Mahmud, L., & Ibrahim, A. (2017). Bioplastics as Better Alternative to Petroplastics and Their Role in National Sustainability: A Review. *Advances in Bioscience and Bioengineering*, *5*(4), 63. https://doi.org/10.11648/j.abb.20170504.13

Liu, Y., Shi, J., Jin, H., & Guo, L. (2023). Current research progress of physical and biological methods for disposing waste plastics. *Journal of Cleaner Production*, *408*, 137199. https://doi.org/10.1016/j.jclepro.2023.137199

Mo, A., Zhang, Y., Gao, W., Jiang, J., & He, D. (2023). Environmental fate and impacts of biodegradable plastics in agricultural soil ecosystems. *Applied Soil Ecology*, *181*, 104667. https://doi.org/10.1016/j.apsoil.2022.104667

Moshood, T. D., Nawanir, G., Mahmud, F., Mohamad, F., Ahmad, M. H., & AbdulGhani, A. (2022). Sustainability of biodegradable plastics: New problem or solution to solve the global plastic pollution? *Current Research in Green and Sustainable Chemistry*, *5*, 100273. https://doi.org/10.1016/j.crgsc.2022.100273

Ritchie, H., & Roser, M. (2022). *Plastics pollution*. Our World in Data. https://ourworldindata.org/plastic-pollution

Tanunchai, B., Ji, L., Schröder, O., Gawol, S. J., Geissler, A., Wahdan, S. F. M., Buscot, F., Kalkhof, S., Schulze, E.-D., Noll, M., & Purahong, W. (2023). Fate of a biodegradable plastic in forest soil: Dominant tree species and forest types drive changes in microbial community assembly, influence the composition of plastisphere, and affect poly(butylene succinate-co-adipate) degradation. *Science of The Total Environment*, *873*, 162230. https://doi.org/10.1016/j.scitotenv.2023.162230