DELIVERABLE

– D1.1 Initial Value Chain and Scenario definition –

Project GA No	101157652
Work Package No	**1**
Deliverable No	**1.1**
Deliverable Name	**Initial Value Chain and Scenario definition**
Lead Beneficiary	**ABORGASE**
Other participants	**EDIFESA**
Version	**3**
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Dissemination level	**PU**
Date due	**28.02.2025**

Document History – Author List

Version	Date	Author	Modifications and comments
0	**26/02/2025**	**ABORGASE/EDIFESA**	**Original Document**
1	**02/04/2025**	**ABORGASE/EDIFESA**	**First technical review**
2	**30/04/2025**	**Miriam Lorenzo (ITENE)**	**Final review coordination team**
3	**06/05/2025**	**ABORGASE/EDIFESA**	**Final version**

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Document classification code

MBS-20250228-D1.1 Initial Value Chain and Scenario definition_rev3

List of Acronyms

BP- Bioplastics

PLA- Poly Lactic Acid

PHA- Polyhydroxyalkanoates

PE- Polyethylene

PP- Polypropylene

PET- Polyethylene terephthalate

PEF- Polyethylene furanoate

CO_2- Carbon dioxide

GHG- Greenhouse gases

EU- European Union

APE Europe- Agriculture Plastics Environment

EC- European Commission

UNE-EN- Una Norma Española-European Norm

PBS- Polybutylene succinate

EPR- Extended Producer Responsibility

NIR- Near-infrared spectroscopy

BREF-BAT reference documents

BAT-Best Available Techniques

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1. Introduction

The main objective of MoeBIOS is to demonstrate novel recycling processes for bioplastics (BPs) to generate high value-added products. To achieve it, the first step is to define the current situation of bioplastics just to establish a starting point. The presence of bioplastics has been studied in different value chains that have been previously identified: **packaging, textile and agriculture**.

This deliverable D1.1, titled "Initial Value Chain and Scenario Definition", is developed during the first period of the project and describes the initial value chain selection and scenario definition that will be used as a **starting point** for the development of the MoeBIOS project. It includes a study of the current situation of bioplastics at a global level, and specifically in packaging, textiles and agriculture, as well as bioplastic waste generation data. In addition, the situation in the coming years has been studied both in the production of bioplastics and in the production of waste at the end of its useful life. Key parameters for the successful implementation of bioplastics for the future have also been established.

As bioplastics production is expected to grow in the next years, this deliverable will be updated at the end of the Project in deliverable D1.2 "Final Value Chain and Scenario Definition" in M42. Its purpose is to evaluate again the content of BP in packaging, textile and agricultural waste streams currently and in the future, in order to compare the results of both deliverables.

2. Current BPs situation

According to the latest available data, the global production of plastics in 2023 was 414 million tons, of which only 3 million tons were biobased plastics (BP). In Europe, 58 million tons of plastics were produced in 2023, 0.8 million tons of which were biobased plastics, representing 1.4% of the total [1]. The figure below shows the evolution of plastics production in Europe from 2018 to 2023:

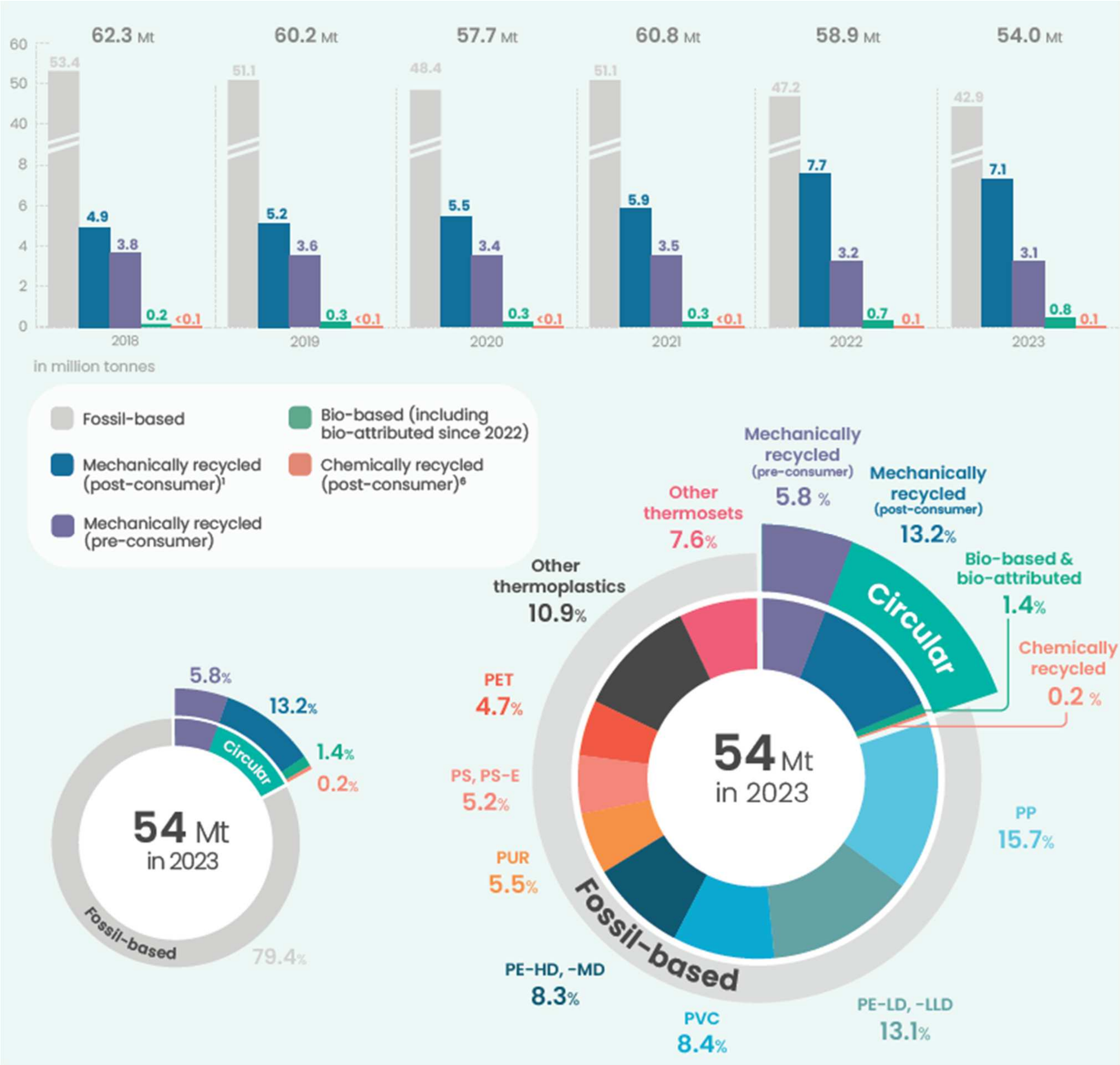


Figure 1. European plastics production by polymer in 2023 [2]

Figure 1 displays how bioplastics production has increased from 0.2 million tons in 2018 to 0.8 million tons in 2023, which means an increase of 300% in five years. This number is expected to continue to grow more sharply in the coming years, as can be seen in Figure 2.

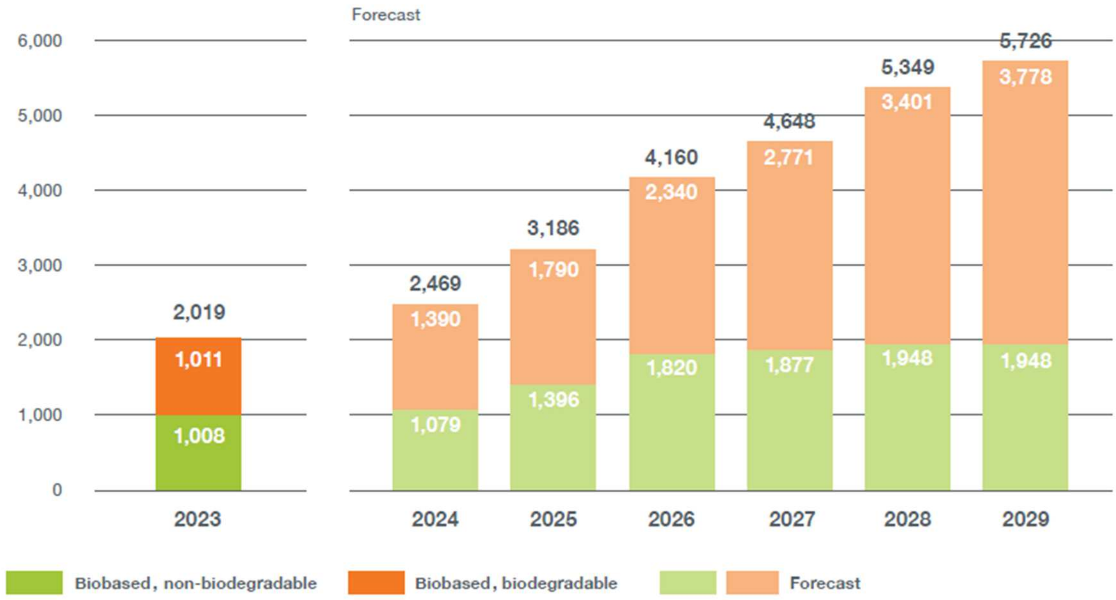


Figure 2. Global Production capacities of bioplastics 2024-2029 in ktons [3]

There are many types of bioplastics able to be an alternative for almost every conventional plastic material. Some of the most used bioplastics are polylactic acid (PLA) and polyhydroxyalkanoates (PHA), as well as other non-biodegradable bioplastics like biobased polyethylene (PE) and biobased polypropylene (PP) (Figure 3).

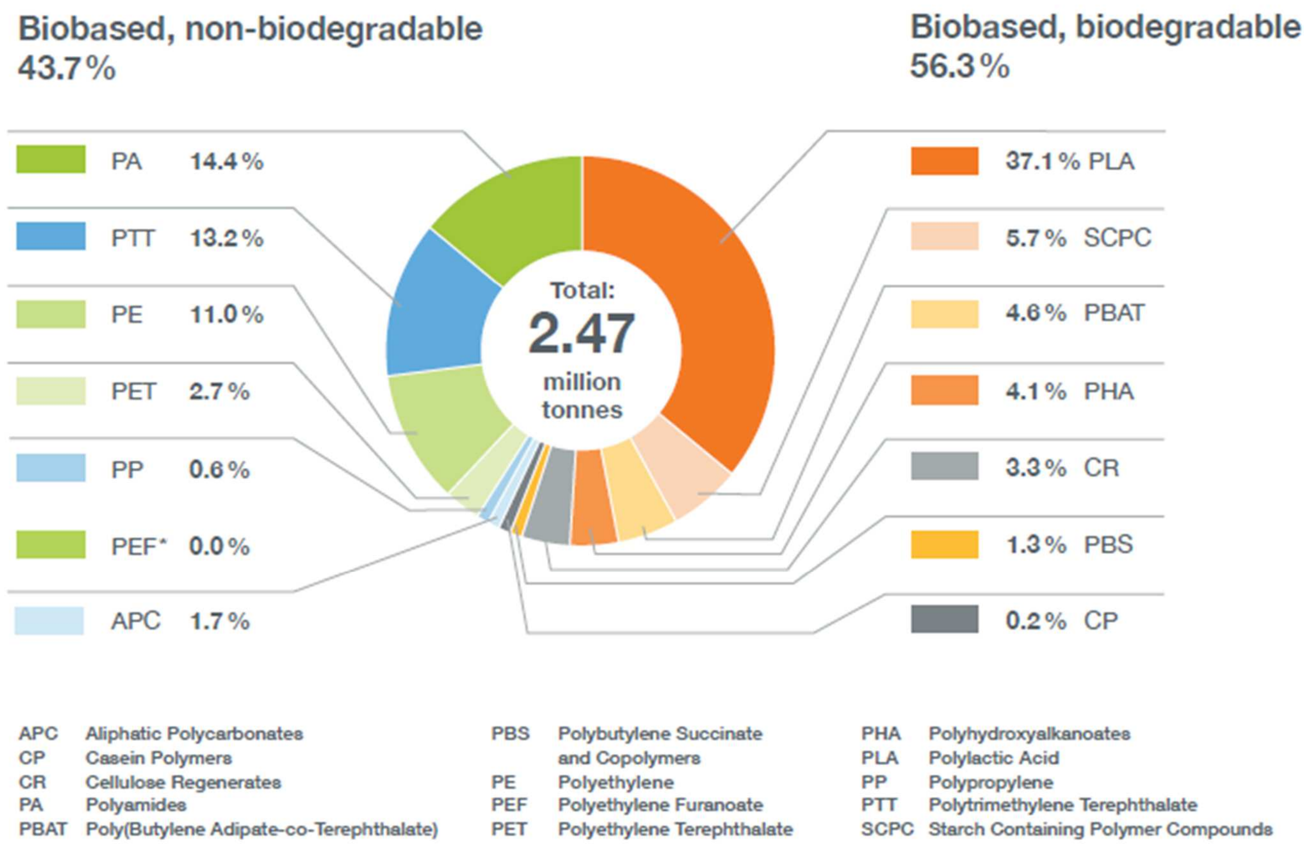


Figure 3. Global production capacities of bioplastics 2024 by material type [3]

Bioplastics are used for a wide range of applications, from packaging, fibres, customer goods to automotive or agricultural products:

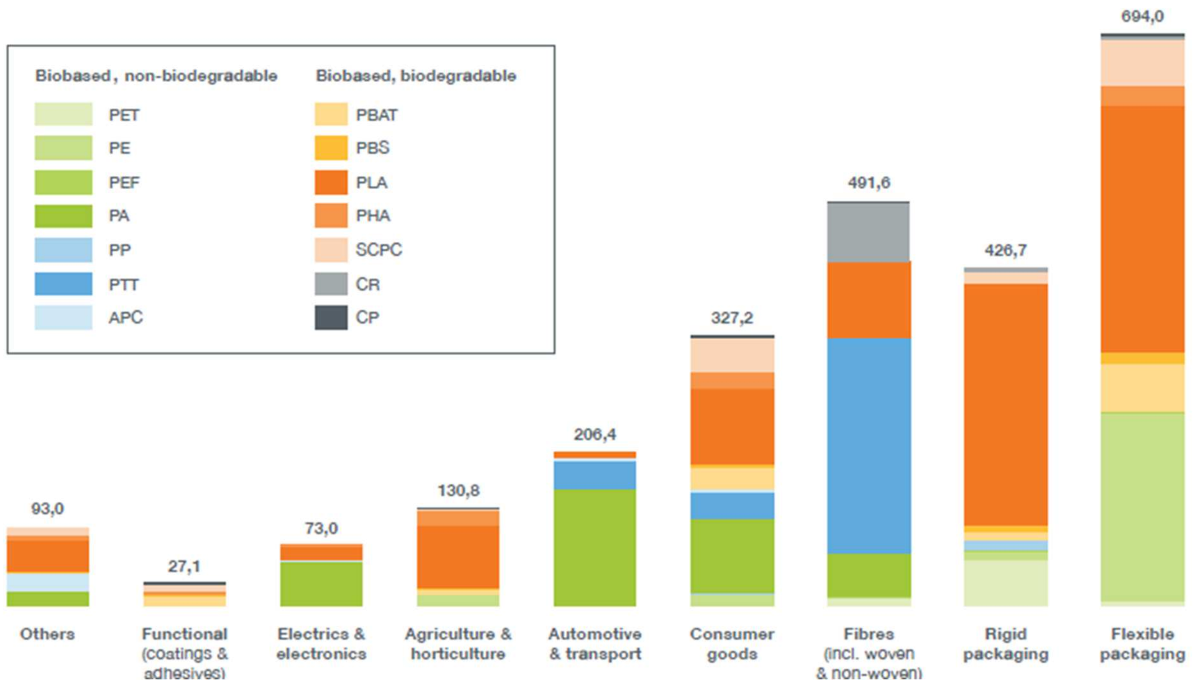


Figure 4. Global production capacities of bioplastics 2024 by market segment (in ktons) [3]

Figure 4 represents the different sectors where bioplastics are used. Packaging is the main sector in which bioplastics are used, followed by the textile and consumer goods sectors. That's why the MoeBIOS project is focusing on packaging, textile and agricultural bioplastic waste streams, which are representative applications of bioplastics.

During MoeBIOS project execution, bioplastics production data will be monitored to compare it with future bioplastics production data that will be exposed in Deliverable 1.2. "Final value chain and scenario definition", where it will be possible to compare bioplastic production data throughout the course of the project.

In order to have a better understanding about bioplastics current situation in Europe, during the subtask 1.1.2. "Engagement of primary producers", Novis and Euro-Funding have created a **questionnaire** with the aim of distributing it through the social media of MoeBIOS project. Initially, this questionnaire was created for the agricultural value chain, but it was finally decided to extend it to other value chains to better understand the characteristics and availability of materials for the project.

The distribution of the questionnaire was carried out by Euro-Funding through different channels: the LinkedIn account of the MoeBIOS project, the project partners' LinkedIn, and the newsletter published on the MoeBIOS project website. It was also shared through the LinkedIn account of the Textile ETP.

At this point in time, only a few responses have been received, and most people who have answered the questionnaire don't work with bioplastics. The main conclusions drawn are listed below:

- Today, few bioplastics are used in packaging, textile and agricultural value chains. However, the majority of respondents expect the amount of bioplastics used in their companies to increase in the next three years.
- In bioplastic packaging, the main problems found are the high cost of bioplastics compared to fossil-based packaging, the limitations in end-of-life packaging management, the lack of regulatory frameworks and the different properties of this biobased packaging which can reduce durability and can limit food contact for certain food products that require longer shelf lives or high temperature resistance.
- Bioplastics in textiles fall short in performance compared to conventional plastic fibers like polyester or nylon. They may lack the durability, strength, and elasticity that synthetic fibers offer, making them unsuitable for high-performance applications or everyday wear. Bioplastics can also be more prone to wear and tear, reducing garment lifespan. Their moisture-wicking, stretch, and heat-resistance properties are typically inferior, limiting their use in activewear or technical fabrics.
- Bioplastics in agriculture face several limitations, in terms of durability and performance. Many bioplastic materials lack the strength and weather resistance required for long-term use in agricultural applications like mulch films or greenhouse covers. Additionally, they may degrade too quickly under harsh outdoor conditions, affecting their effectiveness. The cost of production is also higher compared to conventional plastics, which can limit widespread adoption in the agriculture sector.

2.1. Packaging

Packaging is the largest market segment in the plastic industry, also in bioplastics applications. In Europe, almost 40% of plastics are used for packaging, which is equivalent to 21 million tons [2]. Most of these plastics are fossil-based and they are used only once, which implies that they are not environmentally sustainable.

The EU is trying to solve these problems with circular economy and bioeconomy to improve innovation and research in environmentally friendly packaging systems. New packaging systems with bioplastics have been improved in the last two decades. This packaging includes materials derived from renewable resources and/or biodegradable polymers and ranges from flexible films to rigid materials that have a high potential to produce sustainable packaging [4].

There are different materials used in bioplastic packaging, and they can be divided into three main groups [5]:

1. Bio-based, non-biodegradable materials, such as bio-PE, bio-PET and bio-PEF.
2. Bio-based and biodegradable materials, such as PLA, PHA or starch blends.
3. Fossil-based and biodegradable materials (mostly blended with group 2).

Bioplastics belonging to these three groups can be used in a wide variety of applications, which are detailed below [5]:

1. Rigid packaging: rigid bioplastics are used for cosmetics, beverage bottles or coffee capsules. Most used bioplastics in this section are PLA, bio-PE or bio-PET. This packaging can be recycled by mechanical recycling, which makes it more attractive in the market.
2. Flexible packaging: this type of packaging is frequently used in fresh food such as fruit and vegetables. Other uses of flexible BP packaging are confectionery or dry food, such as tea or muesli.
3. Service packaging: this type of packaging includes cups, plates, cutlery or carrier bags.

2.2. Textile

Textile fibers have undergone a great revolution since 1960 until today. In 1960, around 95% of textile fibres were of natural origin, but the explosion in demand – 650% between 1960 and 2023 – could only be met by synthetic fibres from the chemical and plastics industries. Their share grew from 3% in 1960 to 68% in 2023 and from less than 700,000 tons to 85 million tons/year [6].

This growth has generated a decline in the sustainability of the textile sector, increasing the carbon footprint and causing the appearance of microplastics. That is why, in recent years, an increase in the use of bioplastic textiles has taken place. Bioplastic textiles are an efficient alternative to conventional plastic materials and their applications. It is proven that bioplastic textiles significantly reduced CO_2 emissions as compared to those emitted by conventional plastics.

In the last two decades, as can be seen in Figure 5, the production of biosynthetic textiles has increased slowly, but further growth is expected in the coming years.

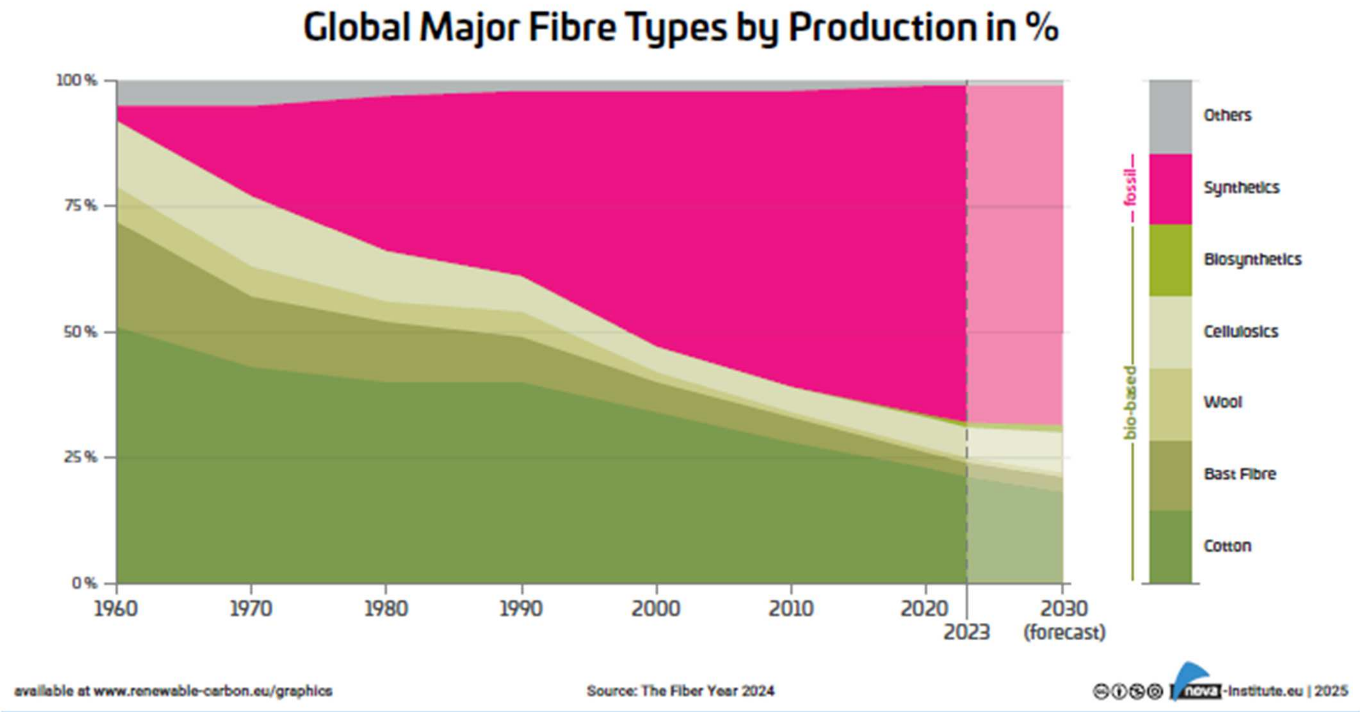


Figure 5. Global Major Fibre Types by Production in % [6]

Bioplastic fibers are an excellent option to replace synthetic fibers because of their range of properties, but the implementation will take decades, as the share today is only below 0.5% [6]. There are many options, but the most widely used biopolymers in textile applications are polysaccharides, proteins, and polyesters. Polysaccharides, like cellulose, are very versatile and can therefore be used in various textile products. Protein-based biopolymers, such as keratin and collagen, are characterized by strong elasticity, resistance and anti-humidity properties that make them suitable for applications in biomedical textiles. Polylactic acid (PLA), from renewable sources such as crops such as corn, sugarcane and wheat, is the most widely used polyester in textiles thanks to its versatility and its characteristics of biodegradability and durability [7].

2.3. Agriculture

Plastic in agriculture is used in a wide range of applications, both for vegetable and animal production. Most of the 28 million farmers in Europe are using plastics in their activities, either for soil or crop protection, increasing yield by favouring root and plant growth, while reducing input consumption such as pesticides, fertilizers, or water use. The total volume of new plastics put on the market is estimated at 713 thousand tons, of which 76% is films. More recently developed, **biodegradable products**, for mulching films and horticulture twine application, account for less than 1% [8]. In the Table 1, there is a list of the main plastic waste found in agriculture:

Table 1. Non-packaging plastic products used in agriculture

Categories	Products	Polymer
Vegetable production:		
Films	*Greenhouses, small tunnels, mulching, flat cover*	4 LDPE, 05 PP
	Biodegradable	Bio based
Protective nets	*Anti-hails, insect-proof, etc.*	2 HDPE
Irrigation	*Pipes and tubes*	4 LDPE
Twine	*Horticulture twine*	05 PP
		Biobased

All agricultural plastics that can be collected and recycled can be substituted with biobased, non-degradable materials. They have the environmental advantage of reducing the dependency on fossil resources and reducing greenhouse gas (GHG) emissions or even be carbon neutral. Moreover, biobased plastics can make a considerable contribution to increased resource efficiency through a closed resource cycle and use cascades [9].

2.4. End of life of bioplastics

According to the latest published data, in the European Union, approximately 16.13 million tons of plastic waste were generated in 2021, which means that each inhabitant generated an average of 36.1 kg of plastic packaging waste. The volume of **plastic packaging** waste generated per inhabitant increased by around 29% (+8.1 kg per person) between 2010 and 2021. Of the 16.13 tons of plastic, only 6.56 tons were recycled, equivalent to approximately 40% [10].

On the other hand, according to the latest available data from 2020, approximately 6.95 million tons of **textile waste** were generated in the European Union, which corresponds to about 16 kg of waste per capita. On average, 72% of this amount, or 11.6 kg per capita, was disposed of by Europeans as unsorted waste, ultimately ending up in landfills or incinerators. In contrast, only 1.95 million tons of textile waste, or 4.4 kg per capita, were separately collected and sent for recovery. Based on a survey conducted among EU Member States, around 82% of the total generated waste comes from the post-consumer sector (both household and non-household), while 18% originates from the pre-consumer sector, including unsold or returned textiles [11].

Regarding agriculture plastics, according to APE Europe, in 2019 the total volume of agri-plastic applications (excluding packaging) placed on the European market was around 722 kt. Of this amount, livestock farming accounted for 55% of the market, and the remaining 45% for crop production. It is estimated that 46.4% of these plastics were recycled, and the rest ended up in landfills or their traceability were lost [12].

To date, there are few to no publications that discuss the current state of the waste management of bioplastics, specifically concerning the numbers that reflect the quantity of bioplastics that manage to achieve the appropriate end of life according to their biodegradable or non-biodegradable, compostable or non-compostable characteristics. Understanding the destination to which bioplastic materials are given, encompassing all the feasible alternatives, could offer a better and complete context for the deliberation of key drivers for the present and future perspective of these materials.

Due to the above, some estimates have been made based on bioplastic production data from the literature, which have been collected in this report:

*Table 2. **Estimated amount** of bioplastic waste generated in Europe*

Value chain	Total plastic waste generation in EU (Mtons/year)	Total plastic waste recycled (Mtons/year)	Recycling ratio	BPs ratio	Total BPs waste production (ktons/year)
Packaging[1]	16,13	6,56	41%	1%	**161,3**
Textile[2]	6,95	1,946	28%	0,5%	**34,75**
Agriculture[3]	0,722	0,335	46%	1%	**7,22**

Part of the waste generated from bioplastics is biodegradable, and another part is not, so the methods used for recycling will have to be focused on the different characteristics of the materials. The best way to treat bioplastics that can degrade under conditions similar to organic waste is to include them in the composting process together with this fraction, while bioplastics that biodegrade under different conditions should be treated using another route.

According to Directive 2008/98/EC on waste, all waste produced in the European Union is applicable to the waste management hierarchy, which determines the priority in relation to waste management processes. Firstly, prevention has the highest priority within the hierarchy, assuming that the most appropriate is to reduce the amount of plastic exploited for use in different production processes, favouring processes that maintain the value of this material in the economy, reducing the production and consumption of virgin material. Next, the management processes that follow the priority sequence are reuse, recycling, recovery and disposal, respectively. Figure 6 schematically demonstrates the order of priority indicated by the hierarchy.

[1] European data for 2021 on packaging plastics waste generation [10].
[2] European data for 2020 on textile plastics waste generation [11].
[3] European data for 2019 on agricultural plastics waste generation [12].

Figure 6. EU waste management hierarchy

Bioplastics follow the same rules and procedures mentioned above, and, therefore, there are different alternatives for their management at their end of [13]:

- Reuse: Bioplastics have great potential for reuse, which means no processing of the waste produced and direct reuse of the product for an activity of the same or different applications than the original one.
- Recycling: there are different methods for bioplastics recycling and the selection of which depends on various technical and economic factors. All recycling methods are complementary and the choice for one of them depends on the specific application, location, the available waste management collection and sorting systems, the recycling technologies available, and the market value of the recycled product. Below are the possible methods available for the recycling process:
    - Mechanical: currently, mechanical recycling is the most used method in the plastics industry due to its operational simplicity compared to other techniques. Additionally, it offers the advantage of utilizing existing processing lines designed for fossil-based plastics. In other words, bioplastics with physicochemical properties identical to their fossil-based counterparts, such as PET, or bioplastics with suitable characteristics for this method, can be processed using the same production line.
    - Organic: organic recycling relies on the biodegradability and compostability of bioplastics, allowing them to undergo composting or anaerobic digestion processes. This method involves the decomposition of bioplastics by microorganisms, resulting primarily in water, carbon dioxide, and stabilized organic matter or compost (when used in composting) or biogas (when applied to anaerobic digestion). It is important to highlight that, within the European regulatory framework, materials intended for biodegradation must comply with the UNE-EN 13432:2001 standard.
    - Chemical: chemical recycling encompasses a variety of processes aimed at converting bioplastic waste into different products. These include thermochemical conversion methods such as pyrolysis and gasification, as well as the recovery of oligomers or

monomers present in bioplastics to create new materials or restore the original composition of the residual bioplastic. This latter approach involves depolymerization processes, such as hydrolysis.

    - Biological: similar to chemical depolymerization processes, biological recycling follows the same principle but utilizes enzymes as depolymerizing agents instead of chemical catalysts. In other words, the breakdown of polymer chains is carried out by enzymes, protein molecules that act on specific substrates, catalyzing one or a small group of chemical reactions. In this case, the enzymatic process cleaves the polymer chain, converting it into oligomeric chains or monomers.

- Energy recovery: if the recycling process is not a viable alternative, energy recovery through incineration is the recommended next process in the waste hierarchy chain. Energy production using bioplastics has an important advantage over fossil-sourced plastics, since the emissions associated with their incineration do not increase the net amount of CO_2 in the atmosphere. The CO_2 emitted by burning bioplastics is associated with a biogenic carbon source, which means that the carbon present in the material comes from biomass and, in turn, the carbon present in the biomass comes from the atmosphere (photosynthesis process), producing a closed carbon cycle that does not produce a net increase of net CO_2 in the atmosphere.
- Landfill: As a last resort, the landfill option serves as the final destination of the bioplastic. This option has the lowest priority in the hierarchy due to the risks of environmental impacts associated with this process, in addition, it represents an end point in the life cycle of the product, which goes against the principles of the circular economy.

3. Value chain definition

Considering the variety of bioplastics that exist on the market, one of the objectives of Task 1.1. "Definition and characterization of biobased waste streams" is to determine the types of bioplastics that are commonly found in packaging, textile and agricultural waste streams. Some bioplastics found in the different value chains studied are biodegradable and they have been discarded to be studied in WP2 due to their difficulty in being recycled by mechanical or chemical recycling.

Besides, fewer bioplastics than expected have been found in packaging, textile and agricultural waste streams, and therefore it has been necessary to define what types of bioplastics are interesting for the MoeBIOS project. To address this task, various **workshops** have been held in which the various partners have discussed the best materials for each value chain. The partners from all value chains who participated in the workshops, along with their respective roles, are summarized in Table 3:

Table 3. Partners involved in all workshops and their roles

PACKAGING WORKSHOP	
ABORGASE/EDIFESA	Packaging waste collection
LEITAT	Development of BPs classification methods
ITENE	BPs recycling methods development
IPC	Contaminants analysis in BP waste and decontamination methods
TRANS SABATER	Recycling of post-industrial and post-consumer waste
SARABIA PLASTICS	Sustainable packaging design and creation
AUSOLAN	Food contact packaging validation
EROSKI	Recycled packaging testing
EUROPEAN BIOPLASTICS	Integrations of the circular value chain
TEXTILE WORKSHOP	
ALIA SERVIZI AMBIENTALI	Textile waste collection
NTT	Textile waste analysis, characterizations and mechanical recycling
PICVISA	Sorting equipment development
LEITAT	Development of BPs classification methods
CHEMOSVIT FIBROCHEM	Recycled textile validation
ITENE	BPs recycling methods development
GREENE W2H2	Thermos-chemical recycling development
TOTALENERGIES CORBION	Recycled bioplastics producers
AGRICULTURE WORKSHOP	
NOVIS	Agricultural waste collection
NOVAMONT	Mechanical and chemical recycling, upcycling and validation
PICVISA	Sorting equipment development
BARBIER	Biobased agricultural plastics validation
TOTALENERGIES CORBION	Recycled bioplastics producers
ASA SPEZIALENZYME	Enzymatic recycling of bioplastics

During these workshops, the best type of bioplastics for MoeBIOS has been determined to define the more adequate materials for recycling methods developed in WP 2 “Novel technologies for enhancing biobased plastics waste recycling”. In this way, the most relevant topics that have been discussed in each workshop are detailed below.

3.1. Packaging workshop

Partners involved in packaging workshops have agreed that the best bioplastic types for the recycling method developed in WP2 are **PLA, PHA, PBS, starch or blends of the above**. This type of material is uncommon in current packaging waste streams, so the problem of obtaining samples to continue with the project has also been discussed.

In addition to the small quantity, bioplastic containers are highly contaminated because they are mixed with other types of waste, such as biowaste, which makes pretreatment for recycling difficult.

In order to properly carry out Task 1.2 “Development of optimized sorting and separation systems” and WP2 “Novel technologies for enhancing biobased plastics waste recycling”, the possibility of acquiring some material samples directly from producers to simulate their everyday use as packaging has been discussed. To carry out this task, waste managers, in this case Aborgase and Edifesa, have contacted various material producers to collect the materials, simulate their everyday use, and send them to the partners responsible for Task 1.2 and WP2, Leitat and ITENE respectively.

This process of sample acquisition and simulation of regular use will be described in detail in D1.3 "Specifications of waste streams".

3.2. Textile workshop

Partners involved in textile workshops discussed the difficulties in obtaining post-consumer clothing made from bioplastics and the high level of contamination that these residues have. They have also highlighted the high heterogeneity that exists in the different fabrics present in textile waste streams. The solution adopted to solve these problems is purchasing pre-consumer clothing from manufacturers and simulating post-consumer waste.

As in packaging waste, waste managers (ALIA) have been in charge of collecting the material to supply it to the partners responsible of Task 1.2 (ITENE) and WP2 (NTT).

Currently, most bioplastic clothing and fabrics are made of **PLA**, so only this material and some blends for MoeBIOS will be considered.

3.3. Agriculture workshop

In this case, agricultural value chain partners discussed how challenging it is to collect, sort and recycle agricultural bioplastic waste due to the fact that the main agricultural products made with bioplastics are mulch films that are not in scope for mechanical/chemical recycling as they are designed to biodegrade in soil. Other products made with bioplastics are starting to be available in the market, but in small amounts and not well-known collection routes. Therefore, some strategies have been explored for sourcing agricultural bioplastic waste streams:

- Collect bioplastic waste streams directly from farmers.
- Source bioplastic waste at industrial composting plants that receive agricultural waste.
- Obtain waste stream from waste managers focused on agriculture.

Novis is in charge of collecting all possible materials in order to provide them to the rest of the partners who are working on Task 1.2. and WP2.

4. Future scenario of bioplastics

4.1. Conservative scenario

To calculate BPs global production in the next five years the Plastics Europe data has been used. With the data available from previous years (2018-2023), the growth trend in bioplastics production over the next few years at a global level has been estimated. In Figure 7 are represented the bioplastics production from 2018 to 2023:

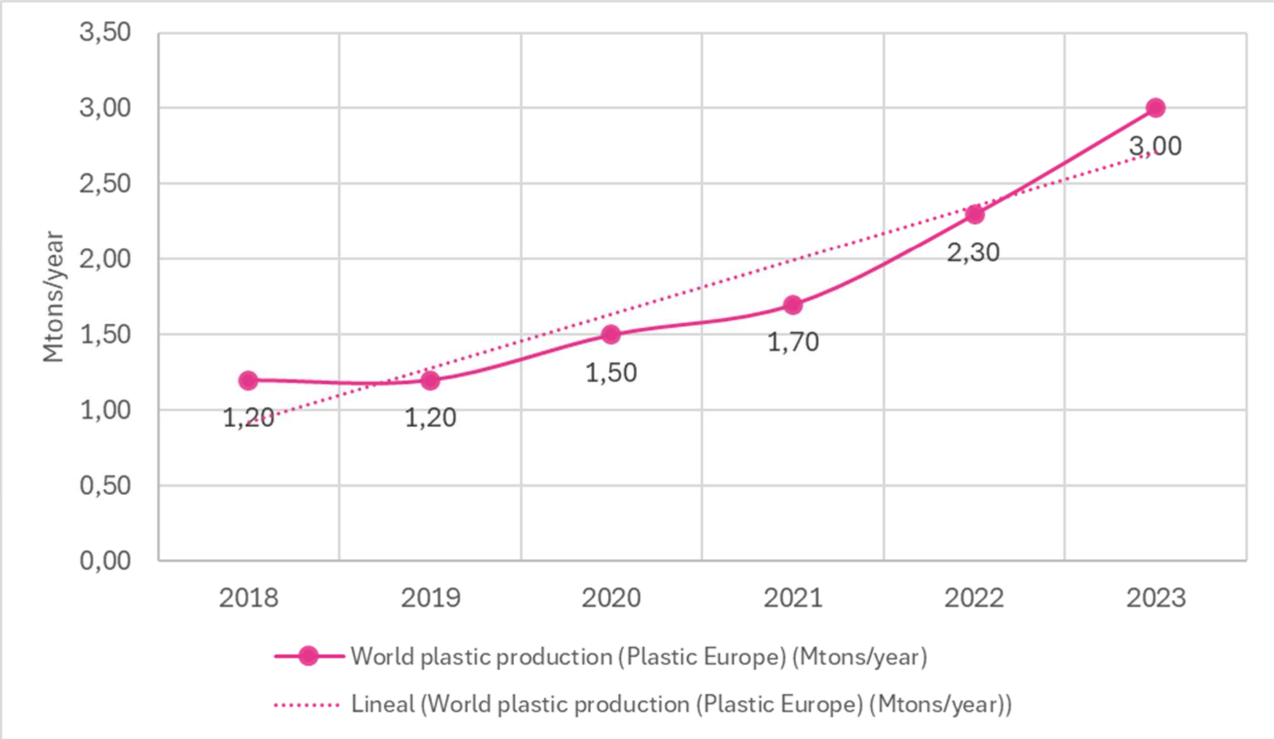


Figure 7. World bioplastic production 2018-2023 [1]

Based on the data presented in Figure 7, a trend line has been determined, resulting in an equation that allows for the projection of bioplastics production beyond 2023. According to the graph, global bioplastics production grew by an average of 21% between 2018 and 2023. Based on the previously mentioned projection, production is expected to continue following an upward trend, with an average annual growth of 14% over the next five years (2024–2029), as illustrated in Figure 8.

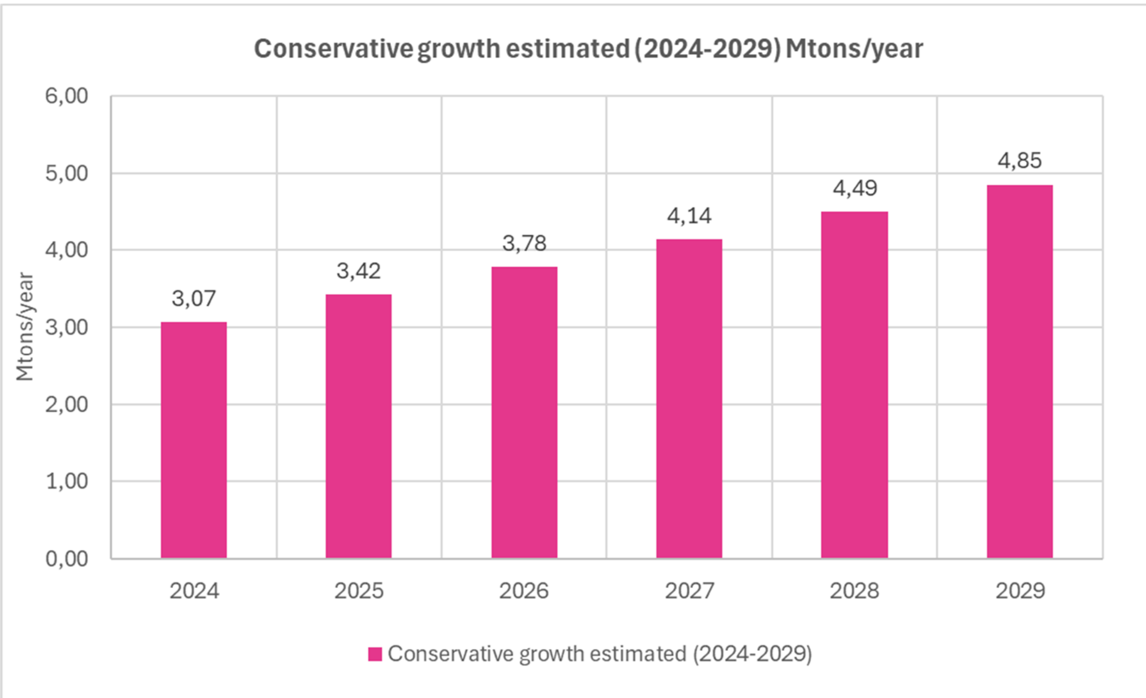
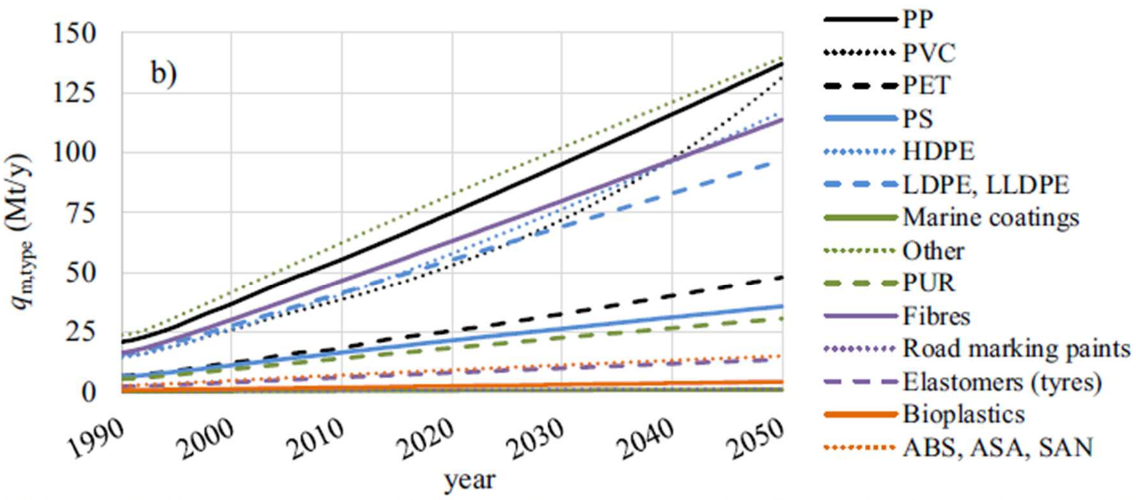


Figure 8. Growth in bioplastics production capacity in the coming years

Based on the data illustrated in Figure 7, global bioplastics production in 2023 amounted to 3.00 million tonnes. Using this value, along with information provided by European Bioplastics indicating that total global plastic production in 2023 was 414 million tonnes [3], it can be concluded that bioplastics accounted for approximately 0.72% of total plastic production that year.

Additionally, using the projection shown in Figure 8, the share of bioplastics in the global context can be estimated for the next five years (medium-term). This estimation is based on the projected global plastic production of approximately 550 million tonnes by 2029 [12][13]. Assuming that global bioplastics production will reach 4.85 million tonnes in 2029, this would represent approximately 0.90% of total plastic production.

Taking into account the above, in the medium term (approximately in five years), it is estimated that the amount of bioplastics produced will not exceed **1% of global plastic production.** In the more distant future, according to the data available in the literature (see Figure 9), bioplastics global production will not be more than **5% of total plastics production**. This information will be updated in Deliverable D1.2 "Final value chain and scenario definition".



ABS: acrylonitrile butadiene styrene, ASA: acrylonitrile styrene acrylate, HDPE: high-density polyethylene, LDPE: low-density polyethylene, LLDPE: linear low-density polyethylene, PET: polyethylene terephthalate, PP: polypropylene, PS: polystyrene, PUR: polyurethane, PVC: polyvinyl chloride, SAN: styrene acrylonitrile resin

Figure 9. Projections of the plastic use by polymer type from 1990 to 2050 [12]

Another important aspect to highlight is the amount of these bioplastics that reach waste plants. Most plastics (and similarly, bioplastics) end up in landfills without being properly treated. In Figure 10 is shown the end of life of plastic waste generated globally for the years 2000, 2020 and 2050. It can be seen that the share of mismanaged waste will decrease in the future years. Almost 50% of plastic waste ends up in landfills [12].

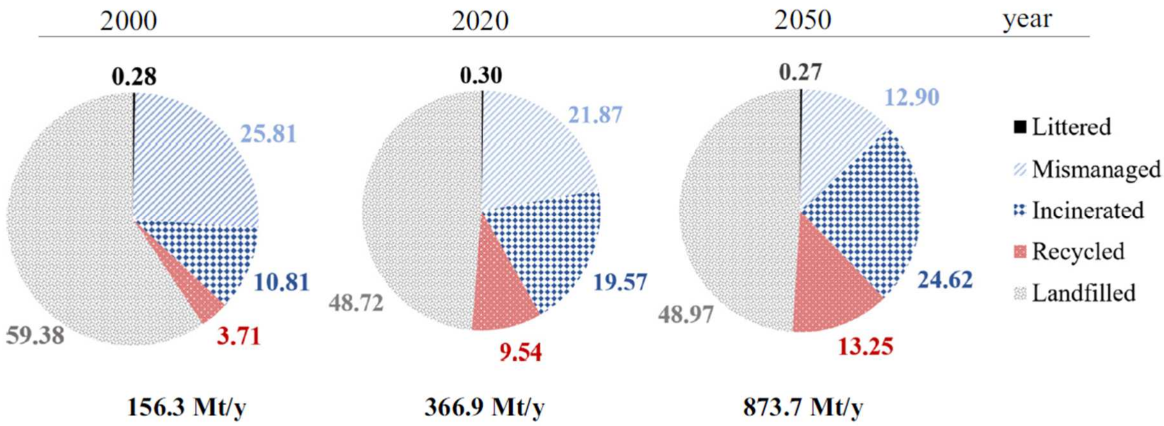


Figure 10. Projections of the global plastic waste by end-of-life fate in the years 2000, 2020 and 2050 [12]

Based on data obtained during the development of WP1, bioplastics are 1% of the plastics found in packaging waste plants, so it is estimated that this value will double in the coming years, reaching approximately 2%, since it is closely linked to the amount of BPs produced. This number is expected to increase more slowly than expected due to the lack of standardization by BP producers and the necessity of adequate legislation to regulate the production and the end of life of bioplastics.

From the point of view of waste managers, bioplastics can be found in different waste fractions depending on the container in which citizens deposit the bioplastics. This implies a greater difficulty for the collection, sorting and recycling of bioplastics, since part of the materials may be out of the system.

If we focus on bioplastic packaging, most of this packaging is currently found in waste from the rest fraction, mixed with all types of waste. Some packaging is also found in the organic fraction and in the packaging fraction. For the operation of the plant, this waste could be properly separated if it is deposited in the rest fraction or packaging containers, since the treatment plants have infrared vision equipment capable of classifying plastics according to the type of material they are made of. The packaging that arrives with the organic fraction would be destined for the composting process or anaerobic digestion, but plastics are not separated.

This distribution of bioplastic packaging among the different waste streams makes it difficult to classify and treat them. Therefore, it is very important to create standards for the manufacture of bioplastic packaging. A possible solution may be the obligation for packaging to include indications of the container in which they must be deposited after the end of their useful life.

Regarding the collection and sorting of bioplastic packaging in waste plants, there are still some **barriers** to overcome in terms of using sorting equipment:

- If bioplastic packaging is small size (less than 80-100 mm), they go through the trommel holes and they will end up with the fines fraction, which is usually the organic matter that will be treated by composting or anaerobic digestion.
- If packaging is black, NIR cannot identify the plastic type.

- Bioplastic films could not be recovered separately either because plastic films are separated by suction with windsifters without differentiating the material from which they are made. This separation is done before NIR detection.
- Within value chains, particularly in the packaging sector, there is significant heterogeneity in material properties, including physical characteristics such as form, dimensions and colour. This variability hinders the integration of all these parameters into the considerations of a single processing unit. Additionally, a similar level of heterogeneity is observed in the contamination of materials arriving at the treatment plant. The irregularity in the type, quantity, and concentration of contaminants negatively impacts the standardization and efficiency of the processing operations.

In textile waste plants, sorting is a simpler task because infrared vision can be used to separate a certain material and collect it. As far as its form is concerned, the heterogeneity in this type of waste is lower than in packaging waste, so it is easier to recover bioplastics for recycling. However, waste textile contamination is a challenging aspect for the development of textile waste sorting and recycling technologies.

In the case of agricultural bioplastic waste, specific agricultural waste management systems are implemented in many countries, which would facilitate the collection of this type of waste in the future, when the use of bioplastics is widespread. Agricultural films have less contamination than packaging waste, which makes the recycling process easier. However, there are many agri-plastics that are black, which complicates the separation of this waste using infrared vision, as with packaging. Likewise, many of the bioplastics end up in composting areas mixed with organic waste, even though their composting time is much longer, which also makes it difficult to identify and collect them.

4.2. Optimistic scenario

In an optimistic scenario, bioplastics production would increase from 0.90% to **1.04% of total plastics production** in the medium term (2029), considering the projected total plastic production of 550 million tonnes in 2029 [12][13] and the bioplastics production estimate for 2029, 5.73 million tonnes, provided by European Bioplastics [3], as illustrated in Figure 11. This means that bioplastics' global capacity will grow by 19.3% on average over five years.

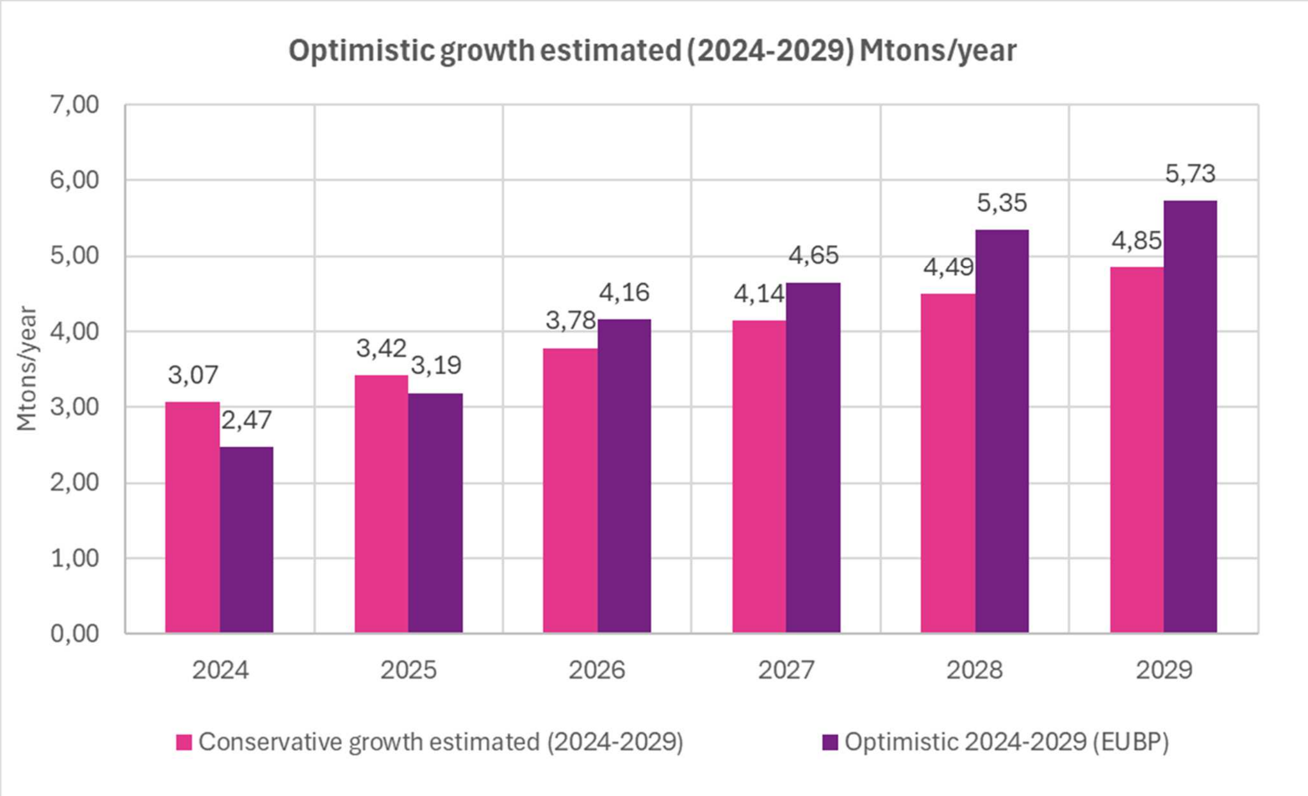


Figure 11. Optimistic growth in bioplastics production capacity in the coming years [3]

In the long term (2050), the target would be to reach approximately **5% of total plastics production**, as inferred from Figure 12, which projects global plastic consumption, and Figure 9, which illustrates the projected bioplastics production. The bibliographic references consulted do not give very optimistic data regarding the production of bioplastics, because there are too many barriers that would have to be overcome in the coming years, both in the design and production of bioplastics and in the management of waste at the end of its life cycle. Therefore, MoeBIOS engages the entire bioplastics value chain, including waste producers, waste managers, the bio-based and bioplastics industry, public authorities, standardization bodies, citizens, and media multipliers to address these barriers.

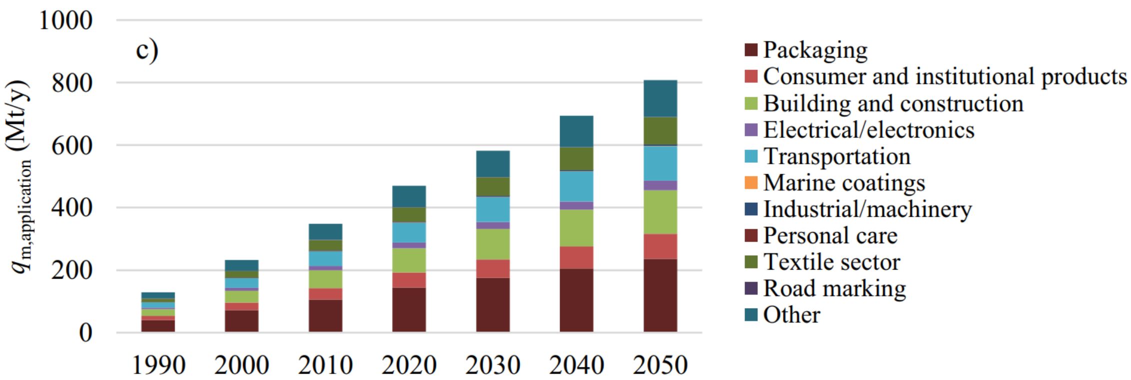


Figure 12. Projections of the plastic use based on application for decades from 1990 to 2050 [12].

In this optimistic scenario, it would be assumed that **a series of measures will be implemented in the future**:

1. Regulations will be created and consolidated by the competent authorities to regulate the production standards of bioplastics, as well as their collection and recycling at the end of their useful life.
2. An Extended Producer Responsibility System (EPR) will be created for bioplastic waste management.
3. Bioplastic packaging will be properly identified so that citizens can deposit it in the appropriate containers.
4. Appropriate technology will be developed to separate and identify bioplastics in waste streams.
5. Waste management plants will be modified to implement new technologies for bioplastics collection and sorting.
6. There will be suitable recycling methods for bioplastics capable of generating new products with high added value.
7. There will be an increased focus on eco-design principles among producers, considering the current perspective and the challenges outlined in the previous section. This approach will facilitate the end-of-life management of bioplastics.
8. Efforts will be made to raise public awareness through educational initiatives on bioplastics, promoting their optimal use. Additionally, these initiatives will create synergies with point 3.

If, through hard teamwork in projects development—such as MoeBIOS—and the exchange of information among different stakeholders, we are able to implement this series of measures, the amount of bioplastic waste generated will increase substantially over the next twenty years, so we must be prepared to address it.

5. Key drivers for future implementation

Based on the information presented in this report, it is possible to identify key drivers that could support the bioplastics market to thrive and potentially reach its full potential within an optimistic scenario. The following factors have been identified by the authors:

- Incorporate bioplastics into the periodic characterizations carried out in waste treatment plants: A common task in waste treatment plants is the periodic characterization of their treatment streams, which involves the classification and quantification of the processed waste. This point suggests that these plants should specifically account for bioplastics separately during the characterization process, quantifying this material independently and identifying in which selective collection streams it is found. Such data, which is currently scarce, plays a crucial role in assessing and justifying management alternatives as well as in shaping future perspectives on bioplastics and their end-of-life treatment.

- Enhancing public education on waste management: Before the development of more efficient sorting and collection technologies for bioplastics, an alternative approach involves raising public awareness and promoting education on bioplastics. By understanding what bioplastics are and their specific properties, citizens would be better equipped to identify different types of bioplastics and determine their appropriate disposal. This, in turn, would facilitate their correct placement in the appropriate waste containers, leading to more efficient selective collection. Improved sorting would ensure that bioplastics are treated alongside materials with similar properties, reducing contamination from unwanted waste in treatment lines and ultimately increasing the efficiency of recycling and valorization processes.

- Development of Bioplastics Recyclability Standards for Their Treatment: In parallel with the first factor, the compilation of data from treatment plants and their outcomes facilitates the development of recyclability standards for bioplastics by substantive bodies. A comprehensive database on bioplastics treatment enables a more detailed analysis of the best available techniques, methods, and technologies for each specific case. This, in turn, supports the creation of sector-specific guidelines, such as a Best Available Techniques reference document, tailored to the bioplastics industry.

- Promotion and Enforcement of Extended Producer Responsibility (EPR) Systems: According to Directive 2008/98/EC, member states may implement Extended Producer Responsibility (EPR) systems either through legislation or voluntary initiatives. These systems require industries to extend their responsibility beyond the production process to include the end-of-life management of their products. In other words, producers of bioplastics are also responsible for ensuring that their products are properly treated after use. This is typically achieved through agreements between manufacturing companies and waste separation, collection, and treatment facilities, facilitated by intermediary organizations that promote such collaborations. Encouraging the adoption of these systems at the member state level could lead to more efficient management of the balance between bioplastics production and actual treatment. Additionally, due to the structured nature of EPR systems, they could improve factors such as waste traceability.

- Incentive of research to ensure the safe use of bioplastics: Advancing research in the field of bioplastics is essential for deepening the understanding of their properties and how they may vary under external influences. A comprehensive study of these factors supports other key drivers, such as the standardization of processes related to the material, whether in production or treatment. This, in turn, ensures greater consistency in outcomes and enhances the safety of bioplastic-based products in their intended applications. Additionally, such research expands the range of potential applications by providing insights into the material's interactions with different conditions, compounds, and products. This allows for the assessment of bioplastics' suitability in industries where fossil-based plastics are widely used, such as the food sector.

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7. Annex I – Questionnaire answers

Table 4. Questionnaire answer (packaging value chain)

ID	Do you use bioplastics in your field?	If so, what amount of bioplastics do you use per year? (in tons)	What change in the amount of bioplastics used do you expect in the next three years?	What challenges and/or limitations do you face or foresee in the use of bioplastics for food packaging sector?	Do you think bioplastics have the potential to significantly reduce the environmental impact of food packaging production?	On a scale from 0 to 10, how much do you agree with the following statement: "Bioplastics are a viable alternative to traditional plastics in the food packaging sector?"	What do you think are the main factors that could favour the widespread adoption of bioplastics in the food packaging sector?	if "others", provide an explanation	Would you be interested in participating in a demo for recycling of your used bioplastic?	If, yes, describe to us the kind of biopastic you are using, and whether the waste could be an eventual mix with conventional plastic, the grade of contamination with other materials, etc.
1	No	0	6	Costs	Yes	8	Cost competitiveness compared to traditional plastics	I didn't select others	No	
2	No	0	7	Conditions of use for food contact and end-of-life management separately from organic waste.	Yes	8	Cost competitiveness compared to traditional plastics	and Technological advancements in bioplastics production and recycling	No	
3	No	0	5	High price of bioplastics compared to fossil materials. In some cases lack of properties of bioplastics, like temperature resistance, fluidity to be processed and mecahanical resistance	Yes	5	Cost competitiveness compared to traditional plastics	Government incentives or policies can influence as well	No	
4	Yes	1	5	Challenges/limitations include the regulatory framework and technology required to obtain such materials from renewable feedstocks.	Yes	5	Consumer demand for sustainable products	N/A	No	
5	No	0	2	Desinformation. Cost. Biodegradability with possibility to affect shelf life. High content of humidity inside the package	No	5	Technological advancements in bioplastics production and recycling;Government incentives or policies;Increased	n/a	No	

ID	Do you use bioplastics in your field?	If so, what amount of bioplastics do you use per year? (in tons)	What change in the amount of bioplastics used do you expect in the next three years?	What challenges and/or limitations do you face or foresee in the use of bioplastics for food packaging sector?	Do you think bioplastics have the potential to significantly reduce the environmental impact of food packaging production?	On a scale from 0 to 10, how much do you agree with the following statement: "Bioplastics are a viable alternative to traditional plastics in the food packaging sector?"	What do you think are the main factors that could favour the widespread adoption of bioplastics in the food packaging sector?	if "others", provide an explanation	Would you be interested in participating in a demo for recycling of your used bioplastic?	If, yes, describe to us the kind of biopastic you are using, and whether the waste could be an eventual mix with conventional plastic, the grade of contamination with other materials, etc.
							awareness of environmental issues;Cost competitiveness compared to traditional plastics;			
6	Yes	1	7	bioplastics in the food packaging sector presents several challenges and limitations. Bioplastics tend to be more expensive to produce than conventional plastics due to the cost of raw materials and less efficient manufacturing processes. Additionally, their performance can be suboptimal, with issues like reduced durability and inadequate barrier properties, limiting their use for certain food products that require longer shelf lives or high-temperature resistance.	Yes	7	Cost competitiveness compared to traditional plastics;	no	No	

Table 5. Questionnaire answer (textile value chain)

Id	Do you use biopastics in your field?	If so, what amount of biopastics do you use per year? (in tons)	What change in the amount of bioplastics used do you expect in the next three years?	What challenges and/or limitations do you face or foresee in the use of bioplastics for textile sector?	Do you think bioplastics have the potential to significantly reduce the environmental impact of textile production?	On a scale from 0 to 10, how much do you agree with the following statement: "Bioplastics are a viable alternative to traditional plastics in the textile sector?"	What do you think are the main factors that could favour the widespread adoption of bioplastics in the textile sector?	if "others", provide an explanation	Would you be interested in participating in a demo for recycling of your used bioplastics ?	If, yes, describe to us the kind of biological-plastic you are using, and whether the waste could be an eventual mix with conventional plastic, the grade of contamination with other materials, etc.
1	Yes	1	5	Challenges and limitations are centered in the regulatory, legal, and environmental framework, which can change as technology advances.	Yes	8	Consumer demand for sustainable products;Increased awareness of environmental issues;Government incentives or policies;	N/A	No	
2	Yes	1	7	Bioplastics in textiles fall short in performance compared to conventional plastic fibers like polyester or nylon. They may lack the durability, strength, and elasticity that synthetic fibers offer, making them unsuitable for high-performance applications or everyday wear. Bioplastics can also be more prone to wear and tear, reducing garment lifespan. Their moisture-wicking, stretch, and heat-resistance properties are typically inferior, limiting their use in activewear or technical fabrics.	No	3	Technological advancements in bioplastics production and recycling;Cost competitiveness compared to traditional plastics;Increased awareness of environmental issues;	No others	No	
3	No	0	2	1.The process of production, it's not clear what to be spend and what will we get 2. Performance in term of use	No	2	Government incentives or policies;Technological advancements in bioplastics production and recycling;Cost competitiveness compared to traditional plastics;Others;	individual awareness	Yes	I am not using and not producing bioplastics. For me... I would rather focus on the use of bioplastics in various packages (it's short-term use) and not focus on adaptation in textile production.

Table 6. Questionnaire answer (agriculture value chain)

ID	Do you use bioplastics in your field?	If so, what amount of bioplastics do you use per year? (in tons)	What change in the amount of bioplastics used do you expect in the next three years?	What challenges and/or limitations do you face or foresee in the use of bioplastics for agriculture?	Do you think bioplastics have the potential to significantly reduce the environmental impact of agriculture production?	On a scale from 0 to 10, how much do you agree with the following statement: "Bioplastics are a viable alternative to traditional plastics in the agriculture sector?"	What do you think are the main factors that could favour the widespread adoption of bioplastics in the agriculture sector?	if "others", provide an explanation	Would you be interested in participating in a demo for recycling of your used bioplastics ?	If, yes, describe to us the kind of biological-plastic you are using, and whether the waste could be an eventual mix with conventional plastic, the grade of contamination with other materials (e.g...
3	No		8	Cost and variety					Yes	Green-house films and plastic boxes. Mixed with conventional plastic from sticks and clamps, and eventual organic matter.
5	Yes	5	7	Total cost compared to conventional alternatives	No	6	Cost competitiveness compared to traditional plastics	It will depend too on the advances of national collection systems for traditional plastics. If these systems are developed fast, the need for bioplastics will not be so urgent	No	
6	Yes	1000	8	- LCA and LCC with bioplastics vs current solution - All biobased are not biodegradable (in biodegradation in soil is targeted) - Mechanical properties of some bioplastics - Climatic conditions - Geographical area - Target culture (in case of mulch film for example)	Yes	8	Cost competitiveness compared to traditional plastics	/	No	
7	No	0	5	Challenges and limitations center on the regulatory, legal, and environmental framework applied to the agriculture sector, which can change as technology advances. I consider this the	Yes	6	Consumer demand for sustainable products	N/A	No	

ID	Do you use bioplastics in your field?	If so, what amount of bioplastics do you use per year? (in tons)	What change in the amount of bioplastics used do you expect in the next three years?	What challenges and/or limitations do you face or foresee in the use of bioplastics for agriculture?	Do you think bioplastics have the potential to significantly reduce the environmental impact of agriculture production?	On a scale from 0 to 10, how much do you agree with the following statement: "Bioplastics are a viable alternative to traditional plastics in the agriculture sector?"	What do you think are the main factors that could favour the widespread adoption of bioplastics in the agriculture sector?	if "others", provide an explanation	Would you be interested in participating in a demo for recycling of your used bioplastics ?	If, yes, describe to us the kind of biological-plastic you are using, and whether the waste could be an eventual mix with conventional plastic, the grade of contamination with other materials (e.g...
				most challenging sector for bioplastic applications.						
8	Yes	1	7	Bioplastics in agriculture face several limitations, in terms of durability and performance. Many bioplastic materials lack the strength and weather resistance required for long-term use in agricultural applications like mulch films or greenhouse covers. Additionally, they may degrade too quickly under harsh outdoor conditions, affecting their effectiveness. The cost of production is also higher compared to conventional plastics, which can limit widespread adoption in the agriculture sector	Yes	5	Cost competitiveness compared to traditional plastics;Increased awareness of environmental issues;Technological advancements in bioplastics production and recycling;Government incentives or policies;	No	No	

Circular Bio-based Europe Joint Undertaking | Bio-based Industries Consortium | Co-funded by the European Union

MoeBIOS project has been funded by the EU and the CBE-JU under grant number 101157652. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CBE JU. Neither the European Union nor the CBE JU can be held responsible for them.