Bio-based feedstock in plastic packaging analysis

Support for (EU) 2025/40 Packaging and Packaging Waste Regulation

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E-mail: *ENV-B01-ARES@ec.europa.eu*

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Support for bio-based feedstock in plastic packaging analysis under the Packaging and Packaging Waste Regulation (EU) 2025/40

Authors: Michael Carus, Christopher vom Berg, Pia Skoczinski, Olaf Porc, Narendar Poranki, Gillian Tweddle, Matthias Stratmann, Lara Dammer and Ángel Puente (all nova-Institute)

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Abstract (EN)

This report assesses the role of bio-based feedstocks in plastic packaging under the EU's Packaging and Packaging Waste Regulation (PPWR), with a focus on technological development and environmental performance. Although seventeen bio-based polymers are commercially available, they represent only ~1% of the global plastics market and account for just 4–5% of biogenic carbon in the EU chemical sector. Production capacity is concentrated in Asia (55%), followed by North America (17%) and the EU27+3 (14%). Despite their limited market share, there are no fundamental technical barriers to using them in packaging. Bio-based plastics offer a 30–70% reduction in greenhouse gas emissions compared to fossil-based alternatives, which supports the EU's decarbonisation and circular economy goals. The report also evaluates the feasibility of setting targets for the use of bio-based materials, their equivalence with recycled materials and how sustainability criteria can be aligned with the Renewable Energy Directive (RED). Key recommendations include setting binding targets for bio-based content, establishing harmonised sustainability criteria, and adapting recycling infrastructure. Leveraging the complementarity of bio-based and recycled content could help to accelerate the EU's transition to a climate-neutral packaging sector.

Abstract (FR)

Ce rapport évalue le rôle des matières premières biosourcées dans les emballages plastiques selon le règlement européen relatif aux emballages et aux déchets (PPWR), en se concentrant sur leur développement technologique et leurs performances environnementales. Si dix-sept polymères biosourcés sont actuellement commercialisés, ils ne représentent toutefois qu'environ 1 % du marché mondial des plastiques et 4 à 5 % du carbone biogénique dans le secteur chimique de l'UE. La production est principalement concentrée en Asie (55 %), suivie par l'Amérique du Nord (17 %) et l'UE27+3 (14 %). Les plastiques biosourcés permettent de réduire les émissions de gaz à effet de serre de 30 à 70 % par rapport aux alternatives fossiles, ce qui soutient les objectifs de décarbonation et d'économie circulaire de l'UE. Le rapport examine la faisabilité de fixer des objectifs pour leur utilisation, leur équivalence avec les matériaux recyclés et l'alignement des critères de durabilité avec la directive sur les énergies renouvelables (RED). Les recommandations clés incluent l'établissement d'objectifs contraignants en matière de contenu biosourcé, l'harmonisation des critères de durabilité et l'adaptation des infrastructures de recyclage. Exploiter la complémentarité entre les contenus biosourcés et recyclés pourrait accélérer la transition de l'UE vers un secteur de l'emballage neutre sur le plan climatique.

Executive Summary

Introduction

The European Union’s Packaging and Packaging Waste Regulation (PPWR) establishes requirements for the life-cycle of packaging as regards environmental sustainability and labelling, to allow its placing on the market. It also establishes requirements for extended producer responsibility, packaging waste prevention, such as the reduction of unnecessary packaging and the re-use or refill of packaging, as well as the collection and treatment, including recycling, of packaging waste.

Article 8 of the PPWR foresees a review of the state of development of biobased plastic packaging both in terms of technological development and environmental performance, taking into account the sustainability criteria of biomass already laid out in the Renewable Energy Directive (RED), in order to propose sustainability requirements for biobased feedstock in plastic packaging and targets to increase the use of such feedstock as well as introduce the possibility of achieving the recycled content targets of the PPWR by using biobased feedstock. This report collects evidence for the review of the state of technological development and environmental performance of bio-based plastic packaging, aiming to provide data-driven insights for a basis on setting criteria that can be applied to bio-based plastic packaging.

Biomass Flows and Market Data

In 2023, global biomass demand reached 13.6 billion tonnes, with bio-based polymers accounting for just 0.023% of the total. Around 3.2 million tonnes of biomass feedstock were used to produce 4.2 million tonnes of bio-based polymers in 2024, primarily from glycerol, sugars, starch, and non-edible plant oils. The EU-27 chemical industry uses around 110 Mt of embedded carbon each year, of which only 4-5% comes from biogenic sources.

The plastics subsector remains over 99% fossil-based. Bio-based polymer production is growing, with global capacities expected to increase significantly by 2030. Nevertheless, bio-based plastics currently account for less than 1% of total plastic production.

Technological development

Bio-based plastics (specifically 17 bio-based polymers) are already today produced and available at the market, using various technologies, such as fermentation, chemical polymerisation and enzymatic processes. Although production costs are generally higher than those of fossil-based plastics, economies of scale and technological advancements are expected to reduce costs over time.

Dedicated bio-based plastics, such as PLA and PEF, offer unique properties (e.g. enhanced barrier properties for PEF) that can outperform their fossil-based counterparts in certain applications. Bio-based plastics can be mechanically or chemically recycled, composted or incinerated. Drop-in bio-based plastics (e.g. bio-PE and bio-PET) are fully compatible with existing recycling infrastructure. However, novel bio-based polymers require expansion and adaptation of recycling infrastructure.

Environmental performance

Bio-based plastics generally result in lower greenhouse gas emissions than fossil-based plastics. For instance, bio-PE and bio-PP can achieve a net negative carbon footprint when accounting for biogenic carbon uptake. Although bio-based plastics reduce the use of fossil resources and GHG emissions, they can increase other environmental impacts, for example impact of land use, eutrophication and acidification. The environmental impact of bio-based plastics depends on the sourcing of the feedstock.

Adopting sustainable practices, such as protecting biodiversity, and maximising land-use efficiency can help to minimise these impacts, as far as possible. Sustainable certification and feedstock diversification are critical to mitigating potential trade-offs, but provide an additional burden for bio-based plastic producers when competing with fossil-based alternatives.

Sustainability Requirements:
The Renewable Energy Directive (RED) provides an established framework for the sustainable sourcing of biomass, including restrictions on high biodiversity and high carbon stock lands. Building on and adapting these criteria for bio-based plastics could help to ensure consistency and credibility.

Existing certification systems (e.g. ISCC PLUS, RSB and FSC) cover environmental, social and land use criteria. These schemes could be used to verify the sustainable sourcing of feedstock for bio-based plastics.

Cascading use – making the most of biomass as a material before recovering its energy – enhances resource efficiency and reduces environmental impacts. Policies should incentivise cascading use to optimise biomass utilisation.

Feasibility of bio-based content targets
Scenarios for 2050 suggest that bio-based plastics could account for 10-30% of plastic packaging, alongside recycled content. Setting gradual, binding targets could stimulate market growth and investment, but learnings from other binding targets (e.g. SAFs) should be considered. There are a few key drivers and barriers when it comes to bio-based content targets in plastics. Key drivers include climate action, consumer demand and circular economy goals. Barriers include higher production costs, limited recycling infrastructure and policy gaps compared to biofuels.

Equivalence with recycled content: bio-based and recycled content targets principally complement each other. Both reduce dependence on fossil carbon, greenhouse gas (GHG) emissions, and facilitate the creation of circular carbon economy. Bio-based plastics also offer unique advantages in specific situations, e.g. food-contact applications and in avoiding toxic substances. An equivalence framework would increase flexibility and resilience, and foster a technology-neutral approach for innovation and scaling.

Recommendations

- **Introduce binding targets for bio-based content in packaging**, linked to sustainability criteria, to stimulate demand and investment.
- **Recognise the equivalence** between recycled and bio-based carbon content to enable a systemic view on solving carbon circularity
- **Harmonise sustainability criteria** building on RED III to ensure reliable transparency on biomass sustainability
- **Support infrastructure development** for collection and recycling of bio-based plastics to further improve circularity and create synergies between recycling and bio-based.
- **Promote R&D and in particular up-scaling to market** to reduce costs and enable innovative solutions

Conclusion

A fully circular plastics system will require virgin non-fossil carbon. Bio-based plastics offer a viable way to reduce the packaging sector's reliance on fossil fuels, but this will depend on supportive policies, sustainable sourcing of feedstocks and development of the necessary infrastructure. The technology is market-ready, but market demand and cost competitiveness to fossil alternatives are critical for scaling to the market. Environmental benefits, in particular climate change mitigation, are clear, but trade-offs must be managed carefully. Sustainability criteria can provide reliable transparency, should be based (and adapted) on the RED framework, and linked to incentives. Here, the EU can accelerate the transition to a circular, climate-neutral economy by integrating bio-based content targets with recycled content requirements. This will require adaptations and development of recycling infrastructure, mainly for dedicated bio-based plastics. A principle equivalence between bio-based and recycled content exists, and such equivalence in the PPWR would strengthen circularity of carbon and defossilisation.

Disclaimer:

„The information and views set out in this study are those of the author(s) and do not necessarily reflect the official opinion of the Commission. The Commission does not guarantee the accuracy of the data included in this study. Neither the Commission nor any person acting on the Commission's behalf may be held responsible for the use which may be made of the information contained therein.“

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Biomass Flows (biogenic carbon use)

Data Sources and Methodology

The mapping of biomass flows and biogenic carbon use in the chemical and derived materials sector on an EU-27 level is based on nova-Institute's comprehensive work on global and European carbon flows (Kähler et al., 2023) and on the joint BIC/RCI biomass studies (Carus et al., 2025; Carus & Porc, 2025); Additional data and information were taken from European Bioeconomy in Figures 2014–2021 (Porc et al., 2024).

Global biomass utilisation

In 2023, the total **global demand for biomass** was around **13.6 billion tonnes**, with bio-based polymers accounting for **only 0.023%** of this. This corresponds to an area share of 0.013%, as bio-based polymer feedstocks are mainly derived from high-yielding crops such as maize and sugarcane, as well as by-products like glycerol and used cooking oil.

Around **3.2 million tonnes of biomass feedstock** were used **to produce 4.2 million tonnes of** (some only partly) **bio-based polymers worldwide** in 2024, mainly from glycerol (31%), sugars (25%), starch (20%), and non-edible plant oils (12%) (Figure 1).

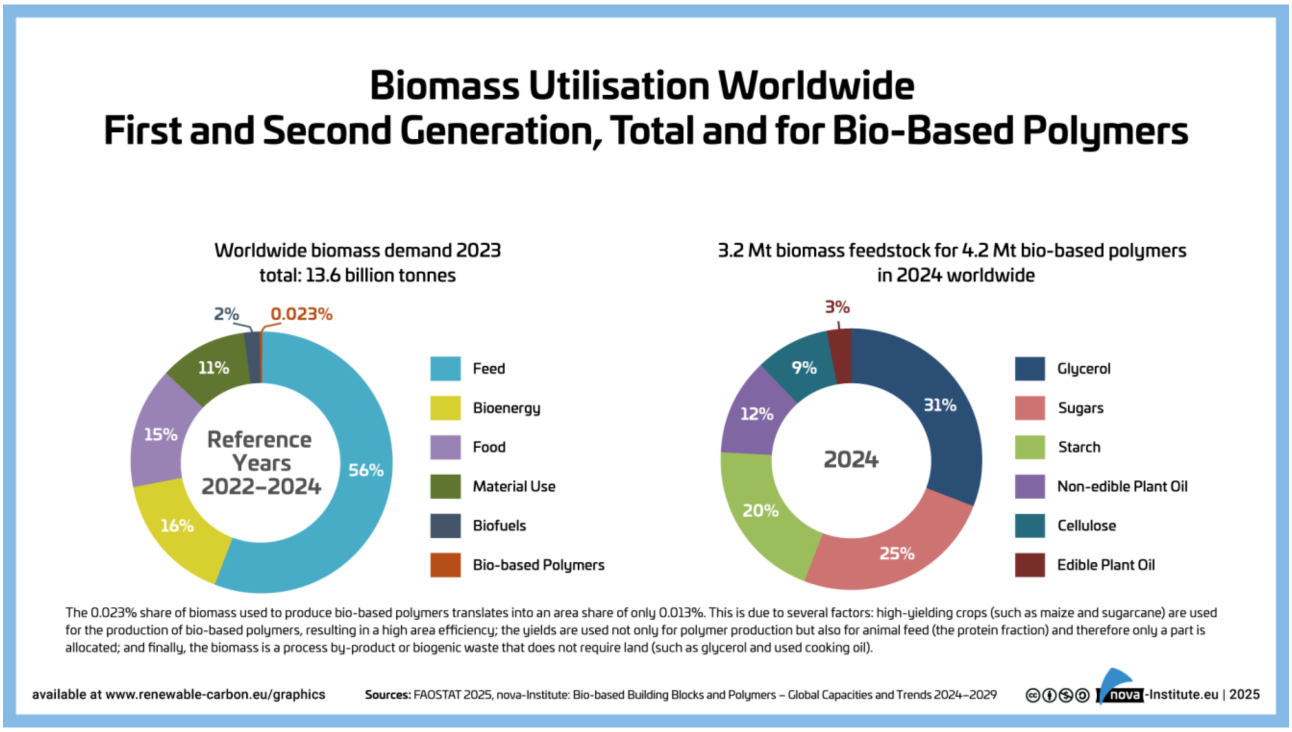

Figure 1: Biomass Utilisation Worldwide (source: Skocszinski et al., 2025)

Biogenic Carbon Use in the EU-27 Chemical Sector

According to the RCI Carbon Flows Report (Kähler et al., 2023 – an update is prepared for 2026), the total embedded **carbon demand for materials and chemicals in the EU-27** amounts to approximately **200 Mt C per year**. Within this total, the **chemical industry** (PRODCOM NACE C20 “Manufacture of chemicals and chemical products”) accounts for roughly **110 Mt C per year**, corresponding to more than half of the embedded carbon in the materials and chemicals sector. Of this, about **5-6 Mt C per year** originate **from biogenic sources**, representing around 4 % of the total embedded carbon in the chemical industry and around 5 % when excluding heavy oil fractions such as bitumen, paraffin waxes and lubricants. The remaining approximately 95 % are fossil-based.

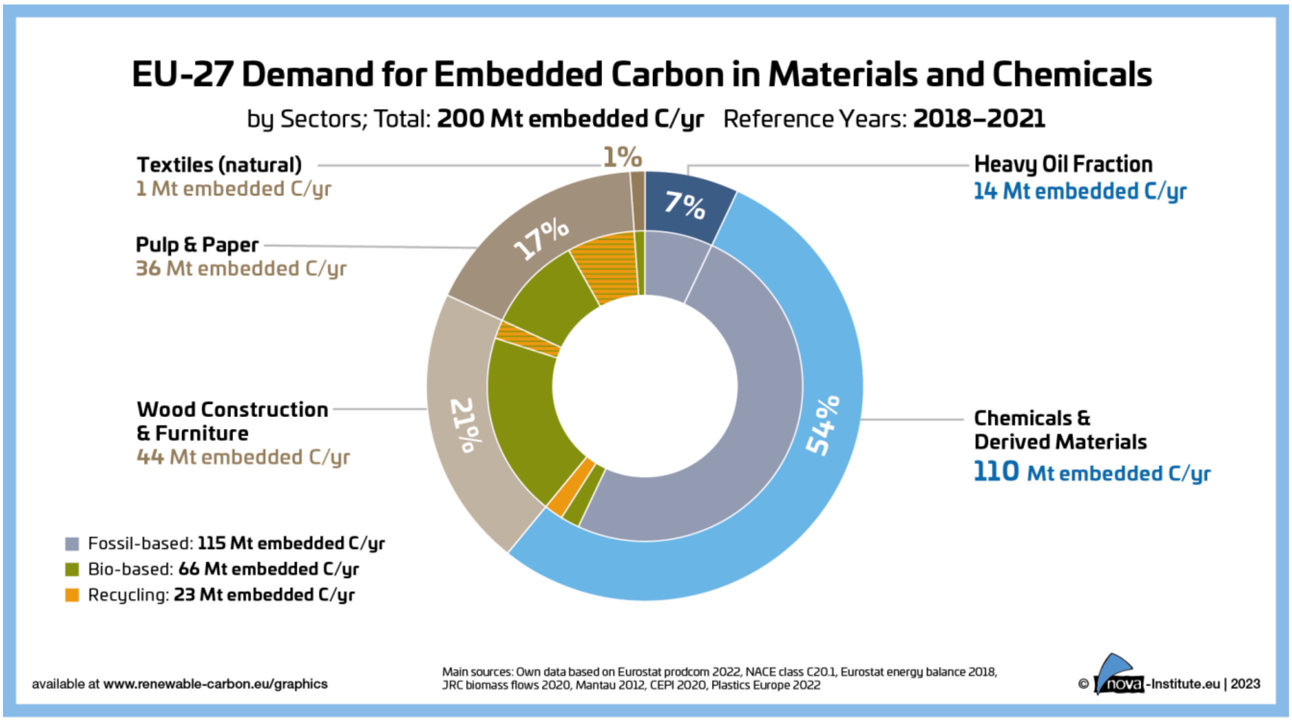

Figure 2: Embedded carbon demand for materials and chemicals in the EU-27 (source: Kähler et al. 2023)

Over 90 % of the biogenic carbon embedded in the chemical sector is concentrated in two PRODCOM NACE classes: 'Other organic basic chemicals' (C20.14) and 'Plastics in primary forms' (C20.16). While the 'Other organic basic chemicals' class has an 8 % bio-based share, the plastics subsector relies almost entirely on fossil feedstocks, with only around 1 % of its carbon content being bio-based. In contrast, the bio-based share in dyes and pigments (C20.12) and synthetic rubber (C20.17) is essentially zero.

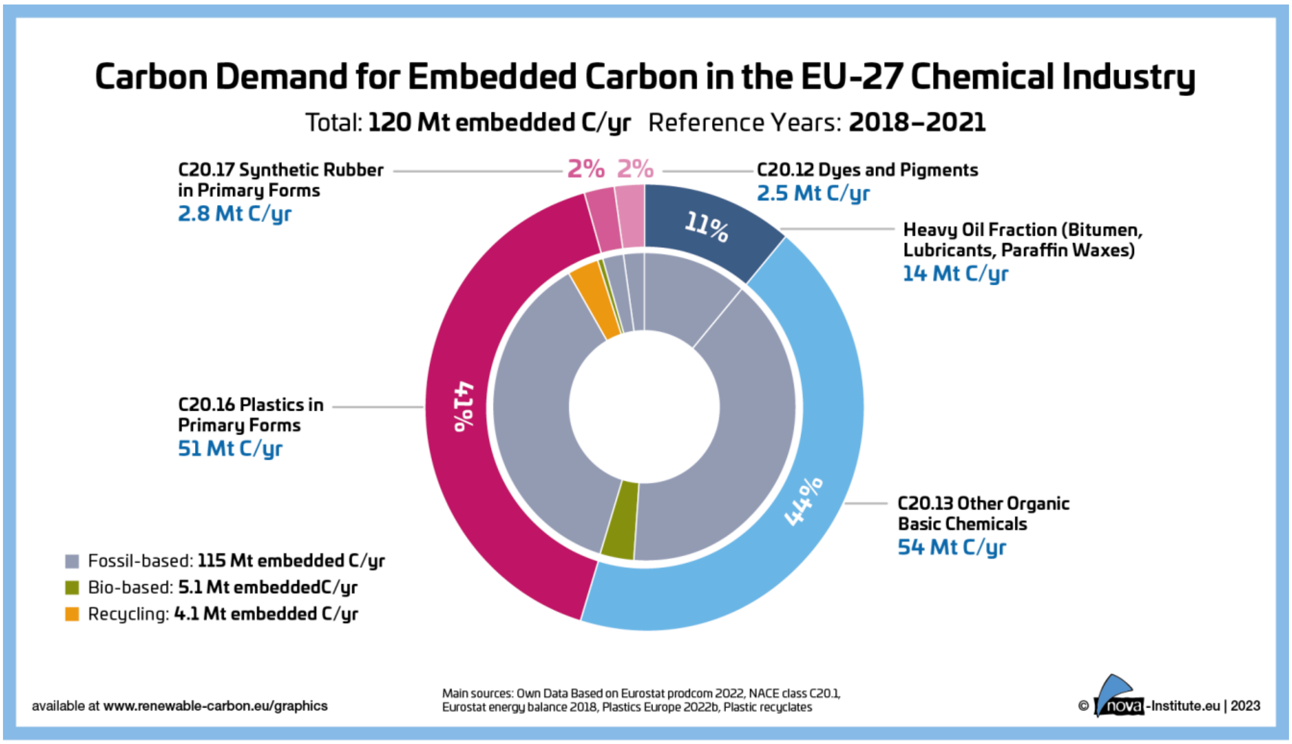

Figure 3: Carbon demand for embedded carbon on in the EU-27 chemical industry (source: Kähler et al., 2023)

These findings are consistent with other analyses by the nova-Institute. According to the BIC/RCI Biomass Report (Carus et al., 2025), the total biomass input to the EU chemical and derived materials sectors amounts to approximately 11.5 Mt dry mass, equivalent to 6.2 Mt biogenic carbon per year. The main feedstock categories comprise starch, sugars, vegetable oils and fats, pulp, and natural rubber. A more detailed overview, based on a combination of literature sources and industry interviews, can be found in Table 1.

Table 1: Overview of most important feedstock consumption in the chemical industry in the EU-27 (in Mt dry biomass and Mt carbon (C)/yr), for the reference year 2023 (taken from BIC/RCI biomass study (Carus et al., 2025))

Feedstock type	Feedstock for Chemicals & derived Materials 2023	Carbon Content	Feedstock for Chemicals & derived Materials 2023
	(Mt dry biomass)	(in %)	(Mt C/yr)
Starch (for bioethanol, for use in chemicals)	0.5	44.4%	0.2
Starch (for fermentation of chemicals, not fermentation of yeast and bioethanol)	1.0	44.4%	0.4
Paper Starch	2.7	44.4%	1.2
Sugar (for bioethanol, for use in chemicals)	0.1	42.1%	0.0
Sugar (for fermentation of chemicals, not fermentation of yeast and bioethanol)	1.3	42.1%	0.5
Vegetable Oils	1.6	76.0%	1.2
Animal Fats	0.4	76.0%	0.3
Chemical Pulp	2.0	44.4%	0.9
Natural rubber	1.1	84.4%	0.9
Glycerol	0.5	39.1%	0.2
Used Cooking Oil (UCO) (for use in steam cracker)	0.3	76.0%	0.2
Palm fatty acid distillate (PFAD) (for use in steam cracker)	0.0	76.0%	0.0
SUM	11.5		6.2

Complementary Eurostat-based data (Porc et al., 2024) confirm a similar magnitude of biomass integration. In 2021, the bio-based share in the chemical industry (C20) accounted for 4.5 % of total production volume. When considering only the organic share of the chemical industry, excluding inorganic products, this corresponds to approximately 8.9 % of organic product volume. These findings are broadly consistent with the embedded carbon analysis from the RCI Carbon Flows Report (Kähler et al., 2023), which estimates a biogenic carbon share of around 4 to 5 % in the chemical and derived materials sector. Minor differences between the datasets result from varying system boundaries and methodological focus. For example, Porc et al. (2024) include product classes such as fertilisers (C20.15), notably organic fertilisers such as manure, which represent some of the largest bio-based products by production volume, as well as other partially bio-based subclasses within the broader definition of the bioeconomy. In contrast, the RCI Carbon Flows analysis excludes these and focuses specifically on embedded organic carbon demand rather than production volumes.

Market Data Collection

The here presented market analysis on bio-based polymers is heavily connected to an accompanying Excel document (Excel Annex I), which provides deeper insights into critical aspects for evaluation of such polymers. In so far as possible, the analysis will consider both worldwide and EU levels. For EU levels, referrals are often made to EU 27+3 (indicating Norway, Switzerland and the UK), which is based on the scope of studies that collected such information. There is little practical difference in market numbers for EU only and the EU 27+3, due to limited production capacities in these three additional countries.

The main market analysis on a worldwide level is included in the columns B to H in the sheet “Bio-based Polymers Worldwide” (see Excel Annex I). All information provided for Production Capacities (column B and C), Average CAGR (column D), Actual Production (column E) and Production Share (column F) are based on the recent, annual market research performed by nova-Institute for the 2026 edition of “Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2025-2030” that will be published in March 2026 (the previous version is Skoczinski et al., 2025). While the data published annually by nova-Institute includes all commercially available 17 bio-based polymers and the 10 applications they are used in including fibres, Plastics Europe and European Bioplastics only show a selection of polymers and applications based on their bio-based plastics and polymers scope (Figure 4 and Figure 5). Please note that the market data available from European Bioplastics and Plastics Europe are based on the data of the nova-Institute.

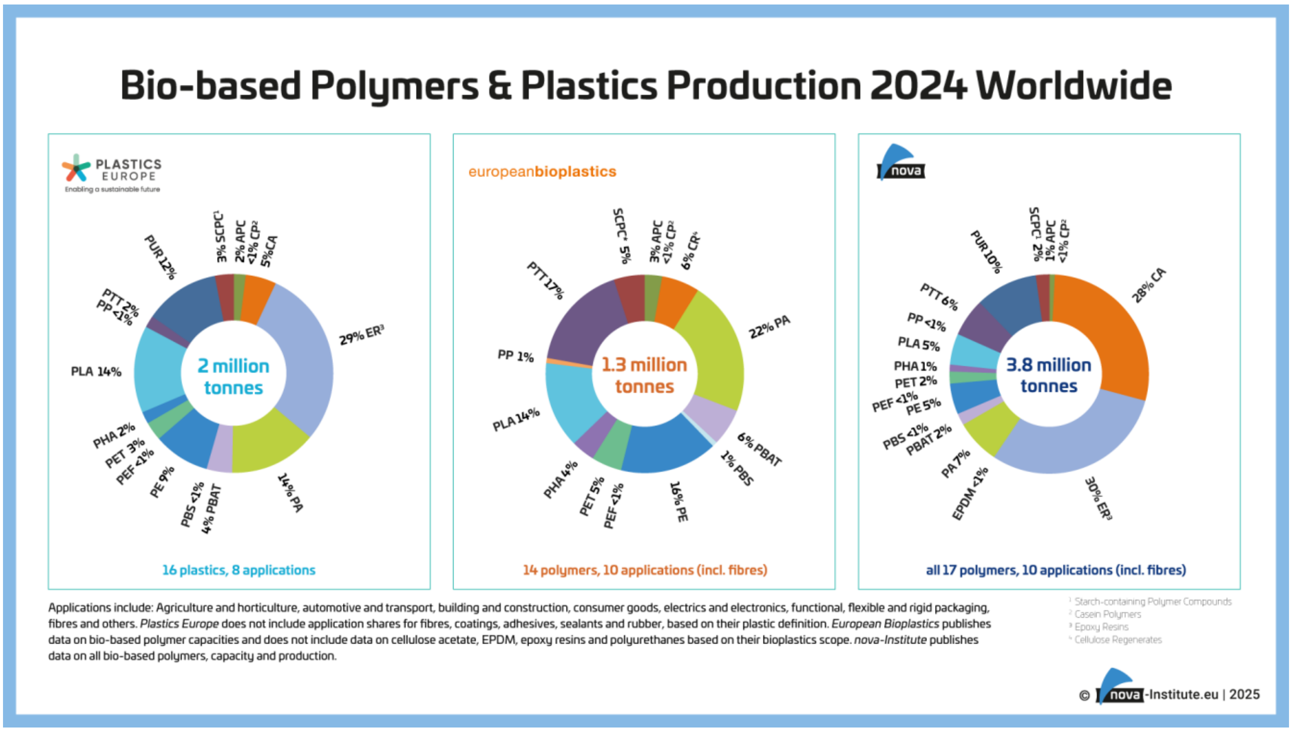

Figure 4: Bio-based Polymers & Plastics Production 2024 Worldwide (source: Skocszinksi et al., 2025).

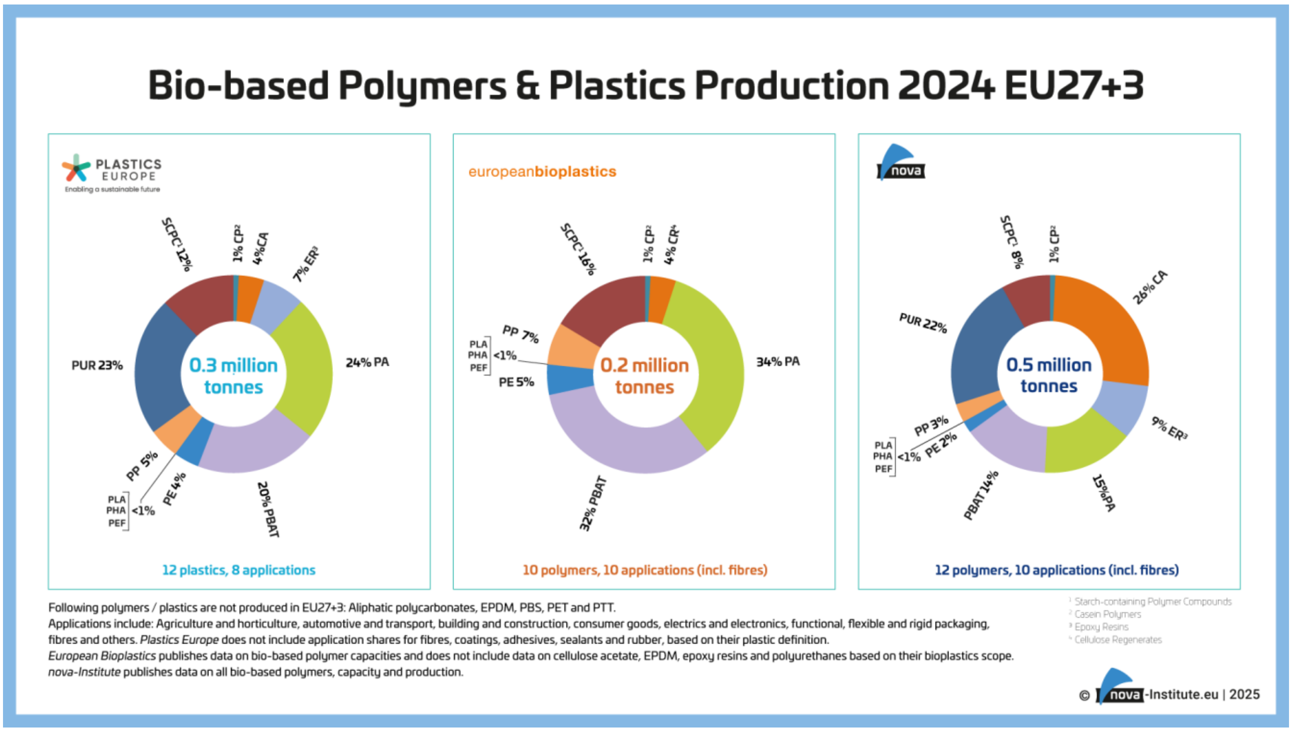

Figure 5: Bio-based Polymers & Plastics Production 2024 EU 27+3 (source: Skocszinksi et al., 2025).

Methodology

The research work on bio-based production capacities and production volumes is based on the analysis and discussion of recent publications, press releases and market studies, questionnaires, face-to-face interviews with experts (many at CEO level), and expert workshops and conferences visited. On the other hand, a broader list of companies is included, e.g. start-ups that have not yet announced volumes but could become leading companies in the future. The overall estimate of polymer production capacity in 2030 is mainly based on the forecasts of companies that are already producing bio-based polymers today or companies that have already announced actions in these areas in the time period between 2025 and 2030. This could lead to an underestimation of future capacities, as the method may overlook new entrants. All market data will be continuously updated by the nova biopolymer expert group and should provide a solid basis for policy-making and future market studies.

Bio-based capacities

For each covered bio-based building block and polymer the report shows the bio-based production capacities per producing company based on interviews, data bases and press releases. For the bio-based polymers, in addition to the numbers for installed total bio-based capacities, also the operating rates and the actual production are shown.

Bio-based production data was deducted from interviews, data bases and press releases. For some polymers the bio-based production is used to calculate a virtual capacity by assuming a 100% operating rate. This is either based on a methodological (calculation-based) issue or due to the aim in drawing a real picture of the bio-based building block and polymer market (e.g. installations where only a part of the installed capacity is used bio-based). The first one applies to CA, epoxy resins, PET and PUR. Here the capacity / production numbers are calculated from the production of the respective building block epichlorohydrin for epoxy resins and diverse polyols for PUR. CA production is calculated backwards from the volume of produced acetate tow. Also, the PET numbers are based on a calculation using the amount of traded bio-based MEG. For the bio-based building block naphtha and the bio-based drop-in polymers EPDM, PE and PP production numbers are reported in order to avoid listing underutilised or not yet fully bio-based utilised high fossil-based capacities (Skocszinksi et al., 2025).

Market Analysis Worldwide (Annex 6, Technological Development, ID 1)

In the following, all columns in the Excel sheets relating to "bio-based polymers" and their contents are briefly described. Please note that between different sheets in the Excel (specifically between bio-based polymers worldwide and bio-based polymers EU 27+3), columns are not always exactly the same. For example, at the global level, Column G provides a production share of bio-based polymers of total polymers, which is not available at EU level. Column G at EU level instead provides an overview of consumption of bio-based polymers within EU. Please further note that some relevant technical information on attributes of bio-based polymers are only listed in the worldwide sheets, and not repeated in the EU sheets, as these aspects are valid independently of location.

Column A – Bio-based Polymer

Lists each of the 17 commercially available bio-based polymers.

Column B – Production Capacities 2025

Shows the total installed production capacity of the respective polymer worldwide in 2025 in tonnes based on data compiled as described "Methodology".

Column C – Expected Production Capacities 2030

Shows the expected total installed production capacity of the respective polymer worldwide in 2030 in tonnes based on data compiled as described "Methodology".

Column D – Average CAGR 2025-2030

Calculated with the total installed production capacities in 2025 and the total expected installed production capacities in 2030 per respective polymer.

Column E – Actual Production 2025

Calculated with the total installed production capacities in 2025 and the estimated average operating / utilisation rate of the installed capacities per respective polymer.

For example: PHAs have a total installed production capacity in 2025 of 108,000 tonnes, the average operating / utilisation rate of all installed capacities was estimated at 70 % resulting in an actual production in 2025 of 76,000 tonnes.

Please note that for the polymers cellulose acetate (CA), epoxy resins, EPDM, partly PE, PET, partly PP and PUR the actual production in 2025 corresponds to the production capacity in 2025. This is either due to a methodological (calculation-based) issue or due to give real picture of the polymer market (e.g. plants where only a part of the installed capacity is bio-based). The first one applies to CA, epoxy resins, PET and PUR. Here the capacity / production numbers are calculated from the production of the respective building block epichlorohydrin for epoxy resins and diverse polyols for PUR. CA production is calculated backwards from the volume of produced acetate tow. Also, the PET numbers are based on a calculation using the amount of traded bio-based MEG. For EPDM, PE (for Borealis and LyondellBasell) and PP production numbers are reported in order to avoid listing underutilised or not yet fully bio-based utilised high fossil-based capacities.

Column F – Production Share of total Bio-based Polymers

Shows the percentage share of the individual respective polymer production of the total bio-based polymers production 2025 worldwide.

Column G – Production Share of total Polymers

Shows the percentage share of the individual respective bio-based polymer production of the total polymers production 2025 worldwide.

Column H – Market Price

Shows the price of the individual respective polymer in €/kg. The market price data presented below are derived from multiple sources, including international trade statistics (e.g. UN Comtrade, USITC for United States, and various other national trade databases from Thailand, Brazil, India, China) where polymers are identifiable through specific 8-digit HS codes. These data are complemented by nova Institut's internal knowledge base, built from industry expert discussions and cross-referenced with available market intelligence.
For certain bio-based polymers, no specific 8-digit HS code exists, or commercial volumes remain too limited to obtain representative price information from market participants. In such cases, pricing data were not available or are excluded.
The prices provided should be interpreted as indicative market averages for first three quarters of 2025, reflecting general trends rather than fixed transactional values.

Table 2: Market Prices for fossil-based polymer (source: UNComtrade EU Market Prices)

Polymer	Avg. EU Market Price (Euro/Kg), 2024
LLDPE	1.18
LDPE	1.18
HDPE/MDPE	1.08
PP	1.09
PET	1.04
PVC	0.85
PS/EPS	0.97
PU Resin	4.17

Table 3: Market Prices for bio-based polymers (source: own nova research and UN Comtrade)

Polymer	Avg. Price (Euro/Kg), 2024
Aliphatic polycarbonates (APC) – cyclic and linear	3
Casein polymers (CP)	N.A
Cellulose acetate (CA)	3.7
Epoxy resins	N.A
Ethylene propylene diene monomer rubber (EPDM)	5.5

Polyamides (PA)	15
Poly(butylene adipate-co-terephthalate) (PBAT)	4.5
Polybutylene succinate (PBS) and copolymers	4
Polyethylene (PE)	2-2,5
Polyethylene furanoate (PEF)	N.A
Polyethylene terephthalate (PET)	2-2,5
Polyhydroxyalkanoates (PHA)	6
Polylactic acid (PLA)	2,5-3
Polypropylene (PP)	3.5
Polytrimethylene terephthalate (PTT)	N.A
Polyurethanes (PUR)	6.5
Starch-containing polymer compounds (SCPC)	4-5

N.A= Data not available

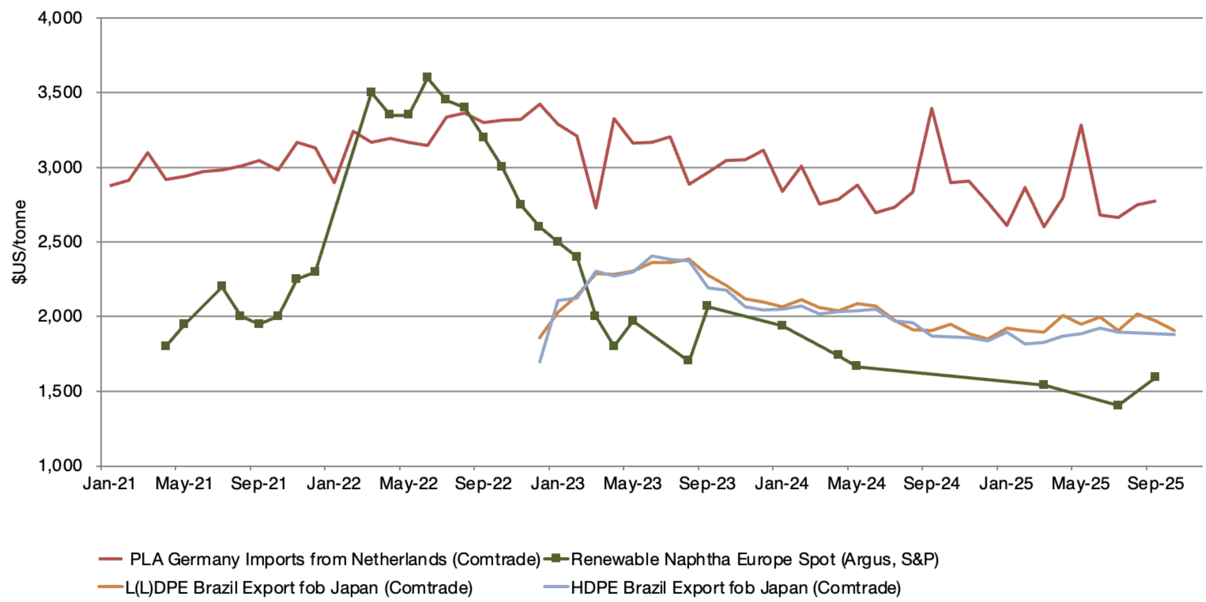

Figure 6: Price chart for PLA (resin), bio-based LDPE and HDPE, and bio-based Naphtha (own nova elaborations via several databases)

While it is difficult to track price fluctuations of all 17 bio-based polymers, some information can be collected for the larger-volume alternatives – see Figure 6. Please take note that prices cannot necessarily be compared directly, and therefore take note of the following comments per polymer:

PLA - the price represents a delivered price for PLA resin to users in Germany (from the Netherlands) who will compound/make items. As there is no PLA production in Europe all material is imported, mainly via Antwerp/Rotterdam/Amsterdam or via Italy. The imported material comes from a small number of large producers either in Asia (Thailand and China - TotalEnergies Corbion and BBCA Futerro) or in the US (NatureWorks). The material is imported into a warehouse in NL for onward distribution. As such the price in the chart includes the cost of transport from Asia and the US as well as any tariffs (though none at present). Prices are based mainly on contracted volumes which have fixed terms over a number of years and this gives a certain level of stability.

L(L)DPE and HDPE. As Braskem in Brazil remains essentially the only merchant producer of bio-based PE, to get price data, exports from Brazil to Japan are examined. As the exports (in the years shown) of PE to japan are exclusively bio-based this means that a price can be calculated from trade data (HS Codes 390110, 390120). Data reported by Brazil exporting to Japan is used, which means that the prices represent a price (fob, freight on board) at the departure port in Brazil and do not therefore include any transport costs. The price will represent sales by Braskem to a few (or maybe only one) company in Japan and we will assume that a simillar selling price would apply to European customers, though price will bvary around this average reported price based on the offtake volume of the customer and negotiated contract price.

bio-based Naphtha - is much more difficult to track. This price information, based on contracts between bio-naphtha producers and their customers is collected by price reporting agencies such as Argus, though is generally not publicly available. For this report, nova has collected information in the public domain (articles, sample publications) from e.g. Argus, S&P, and therefore only a limited number of data points can be referred to. The trend is shown. Bio-based PP in Europe is produced up to ~30-40% bio-based content by batchwise operation of a small steam cracker and/or production from bio-based propane (also a HVO/HEFA byproduct) and the propane price follows the same trend as bio-based naphtha. Bio-naphtha is also a relevant pre-cursor for Sustainable Aviation Fuels, where Sweden reduced their quotas to align with EU targets and thus guaranteed demand dropped accordingly. The partly bio-based PP is considerably more expensive than the bio-based naphtha because of the difficulties in stacking up enough customers for a bio-based PP 'run'. and the additional work in ensuring segregation of feedstock and product storage and transport. The price probably represents a delivered price to the customer for bio-based naphtha.

Where data comes from trade data sources (this report refers to UN Comtrade), there is always the possibility of incorrect data/errors in reporting so not too much emphasis should be given to individual one month price spikes and dips - the overall trend is what is of interest.

Column I – Rough Market Value 2025

Shows the market value of the individual respective polymer worldwide in € million. Calculated with the market price and the actual production of the respective polymer 2025. Table 4 shows comparative market values for fossil based polymers (Source: Plastics Europe, 2025)

Table 4: Market value for fossil based polymers (source: Plastics Europe, 2025)

Polymer	Global annual Production, million metric tons, 2024	Estimated Global Market value, Euro million, 2024
LLDPE/ LDPE	59.9	70,68
HDPE/MDPE	52.2	56,38
PP	81.9	89,27
PET	26.7	27,77
PVC	55.2	46,92
PS/EPS	22.0	21,34

PU Resin	22.8	95,08
Other Thermopsets, thermoplastics	66.4	N,A
Recycled, Bio-based and attributed	44.4	N.A

Table 5: Market value for bio-based polymers (source: own nova research)

Polymer	Global annual Production, metric tons, 2024	Estimated Global Market value, Euro million, 2024
Aliphatic polycarbonates (APC) – cyclic and linear	38,000	114
Casein polymers (CP)	3,600	N.A
Cellulose acetate (CA)	1,111,000	4070
Epoxy resins	1,350,000	N.A
Ethylene propylene diene monomer rubber (EPDM)	1,000	6
Polyamides (PA)	349,000	4,275
Poly(butylene adipate-co-terephthalate) (PBAT)	79,000	356
Polybutylene succinate (PBS) and copolymers	13,000	46
Polyethylene (PE)	219,000	130-163
Polyethylene furanoate (PEF)	2,000	N.A
Polyethylene terephthalate (PET)	70,000	140-175
Polyhydroxyalkanoates (PHA)	76,000	270
Polylactic acid (PLA)	385,000	350-438
Polypropylene (PP)	23,000	56
Polytrimethylene terephthalate (PTT)	270,000	N.A
Polyurethanes (PUR)	411,000	2470
Starch-containing polymer compounds (SCPC)	76,000	264-330

Additional Information

The columns, J, K, L, M and N as well as table "Bio-based Polymers Applications" give additional information for each of the respective polymers regarding their main application, application in packaging (rigid and flexible), bio-based share and their type, the classification into drop-in, smart drop-in and dedicated polymers. All information provided for main application (column J), application in packaging (rigid and flexible) (column K and L) and bio-based share (column M) and table "Bio-based Polymers Applications" are based on the recent, annual market research performed by nova-Institute for the 2026 edition of "Bio-based Building Blocks and Polymers – Global Capacities, Production and Trends 2025-2030" that will be published in March 2026 (the previous version is Skoczinski et al., 2025). Information provided on the type, the classification into drop-in, smart drop-in and dedicated polymers (column N) are based on the nova-Institute report "Bio-based drop-in, smart drop-in and dedicated chemicals" (Carus et al., 2017).

Column J – Main Applications

Shows the main application of the respective polymer.

Column K and L – Application Share in Flexible and Rigid Packaging

Shows the share of the respective polymer that is used in rigid and flexible packaging. Please note that polymers aliphatic polycarbonates – cyclic and linear (APC), epoxy resins, EPDM, PA, PTT and PUR are not used in packaging applications.

Column M – Bio-based Share (in the polymer)

Shows the bio-based share or more specifically the bio-based content is, according to the Technical Committee 411 “Bio-based products” within the European Standardisation Committee (CEN/TC 411) “Bio-based products – Vocabulary” (EN 16575:2014), defined as the fraction of a product that is derived from biomass. Based on this a bio-based product can be fully or partly derived from biomass. A partly bio-based polymer consists of a bio-based and a fossil-based part and has a lower bio-based content than a fully bio-based polymer. The bio-based content is determined by the polymerisation reaction and does not vary regional or based on different polymer producers. As an example: Bio-based PET is only available with a 30 % bio-based content, because only the monoethylene glycol (MEG) is available bio-based, the other building block terephthalic acid is only available fossil-based. The 30 % bio-based content is determined by the amount of needed monoethylene glycol for the polymerisation of PET, the bio-based content can only be increased if the terephthalic acid will be available and used bio-based. An overview is provided in Figure 7 but concrete and more reliable information should be taken out of the Excel Annex I.

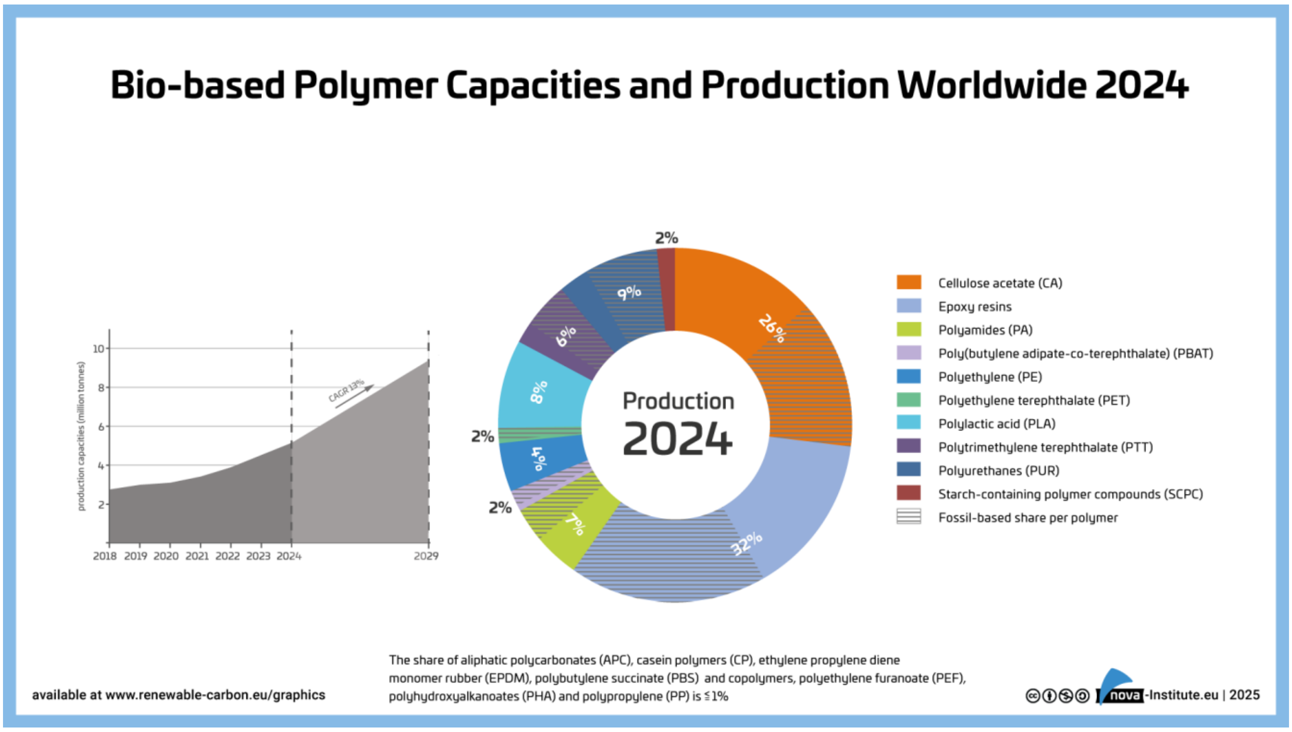

Figure 7: Bio-based Polymer Production and Bio-based Shares 2024 (source: Skocszinksi et al. 2025).

Column N – Type (drop-in, smart drop-in, dedicated)

Shows the classification of the respective polymer into drop-in, smart drop-in and dedicated polymers.

Bio-based drop-in chemicals are bio-based versions of existing petrochemicals which have established markets. They are chemically identical to existing fossil-based chemicals. Bio-based polymers in this group: EPDM, PE, PET and PP.

Smart drop-in chemicals are a special sub-group of drop-in chemicals. They are also chemically identical to existing chemicals based on fossil hydrocarbons, but their bio-based pathways provide advantages compared to the conventional pathways. We consider drop-in chemicals to be 'smart drop-ins' if at least two of the following criteria apply:

Their production requires significantly less energy compared to other production alternatives.

Time-to-product is shorter due to shorter and less complex production pathways compared to the fossil-based counterpart or other drop-ins.

Less toxic or harsh chemicals are used or occur as by-products during their production process compared to the fossil-based counterpart or other drop-ins.

Bio-based polymers in this group: epoxy resins, PA, PBAT, PBS(X), PTT, PUR based on other polyols than natural oil polyols (NOP).

Dedicated bio-based chemicals are chemicals which are produced commercially via a dedicated pathway and do not have an identical fossil-based counterpart. As such, they can be used to produce products that cannot be obtained through traditional chemical reactions and products that may offer unique and superior properties that are unattainable with fossil-based alternatives. Bio-based polymers (platforms) in this group: APCs, CP, CA, PA (based on 1,5-pentamethylenediamine (DN5) and sebacic acid), PEF, PHA, PLA, PUR based on NOP and SCPC.

Table "Bio-based Polymer Applications"– Column B – Share of Different Market Applications Worldwide 2025

Shows the share of the different market applications in 2025 worldwide based on the share of the respective polymers used for this application.

Table "Bio-based Polymer Applications"– Column C – Share of Different Market Applications EU 27+3 2025

Shows the share of the different market applications in 2025 EU 27+3 based on the share of the respective polymers used for this application.

Market Analysis EU 27+3 (Annex 6, Technological Development, ID 1)

The columns in the table "Bio-based Polymers EU 27+3" (see Excel Annex I) and their contents are similar to the described columns in the section "Market Analysis Worldwide (Annex 6, Technological Development, ID 1)" with the focus being on EU 27+3 instead of worldwide. Therefore, they are not described in detail again for EU 27+3. With column G being the exception.

Please note that the polymers aliphatic polycarbonates – cyclic and linear (APC), EPDM, PBS, PET and PTT are not produced in EU 27+3 currently. Additionally, PLA is currently not produced in EU 27+3, but expected to be produced in EU 27+3 in 2030 by the company Futerro in France.

Column G – Consumption EU 27+3

The consumption figures for bio-based polymers in EU 27+3 are derived primarily from international trade data where polymer specific 8-digit HS codes enable tracking of import and export volumes. The total EU 27+3 consumption values were calculated using the formula:

$$\text{Total Consumption} = \text{Domestic Production} - \text{Exports} + \text{Imports}.$$

For certain drop-in polymers such as EPDM, epoxy resins, polyamides, polyethylene, and polypropylene, PET etc. this approach is challenging, as trade data do not distinguish between petrochemical based and bio-based polymers. Moreover, for several biopolymers such as Aliphatic polycarbonates, Casein polymers, PHA etc. the relevant HS codes are aggregated under broader categories, making precise segregation of bio-based polymer volumes difficult.

The consumption data therefore represent best available estimates based on 2024 trade data, as trade statistics for the preceding year are typically released only in March of the following year. Consequently, data for 2025 will not be available until March 2026.

Task 2: Desk Research on State of Technological Development and Environmental Performance of Bio-based Plastics Packaging

Technological Development

Production and manufacturing costs of bio-based plastics (Annex 6, Technological Development, ID 2)

Production and manufacturing costs for the bio-based plastics are not readily available in existing literature. Overall, there is limited data available across individual sectors (automotives, packaging, construction, …) but not at the individual product level. While a deeper dive into individual products might be theoretically conceivable, it would require significant effort and might still come with a relevant number of assumptions and estimations that limit reliability. The calculation of production costs for the various polymers is therefore not possible within the scope and budget of this project. The data required for this is not available and would have to be modeled at great expense. The data shown in the table are the prices as they can be researched on the market and in databases.

Share of bio-based plastic use in long-lived products and short-lived products (Annex 6, Technological Development, ID 3)

There is little to no data available on the share of bio-based plastic in long-lived and short-lived products, at polymer or product level. That said, Figure 8 below illustrates how experts from the international nova Biopolymer Expert Group estimate the market share distribution for the 17 bio-based polymers across market applications. It allows to draw some conclusions on bio-based plastics in long-term and short-term applications, based on the assumption that e.g. plastics in electrics and electronics, in consumer goods (e.g. toys), in automotives and transports, in buildings and construction, have presumably higher life-time durations, while applications in rigid and flexible packaging, and agriculture / horticulture have rather shorter life-times. Fibres and Functional polymers can cover a wide range of applications, so their lifespan depends on application in the end-segment – fibres could e.g. range from short-life textiles (like non-woven wipes and cigarette filters (the main application of CA) to long-life products (like carpets and apparel).

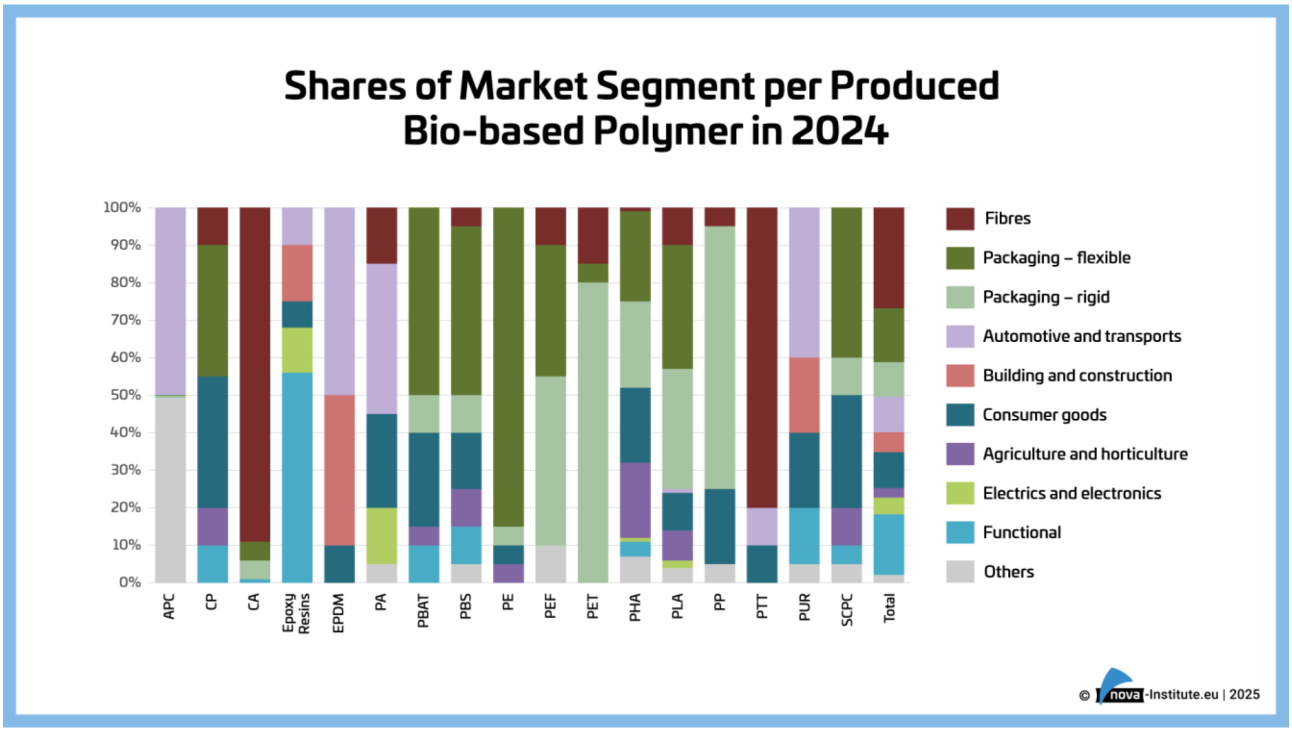

Figure 8: Share of Market Segment pr Produced Bio-based Polymer in 2024, Global (source: Skocszinksi et al. 2025).

Mechanical properties of non-drop-in bio-based plastics (Annex 6, Technological Development, ID 7)

Non-drop-in bio-based plastics include smart drop-ins and dedicated plastics. As described in 0 Market Data Collection, Column N – Type the difference between drop-ins and smart drop-ins is only the more efficient production process, the resulting polymer and its properties stay the same as for the fossil-based counterpart. Bio-based smart drop-ins as epoxy resins, PBAT, PBS and PTT have the exact same mechanical properties as their fossil-based counterpart. This looks different for the bio-based dedicated polymers casein polymers (CP), cellulose acetate (CA), PEF, PHA, PLA and SCPC. These polymers do not have fossil-based counterparts and some of them have unique properties for a specific niche application where they do not have and cannot compete with fossil-based polymers, as these are just not having the necessary properties to being used in this application. An example for this is cellulose acetate (CA) that is used in filter applications, mainly for the production of cigarette filters. Others as PHA and PLA exist or are being produced in a large variety of different grades to meet a specific requirement for substituting a fossil-based plastic application. Here the given timeframe of this project does not allow an in-depth analysis of all available grades and their mechanical properties compared to the fossil-based plastics. Polyethylene furanoate (PEF) is known or marketed as a 100 % bio-based substitute for PET, here a direct comparison has shown that PEF has similar properties as PET and even outperforms in some. PEF has enhanced barrier, mechanical and thermal properties. The barrier properties of PEF, which are ~10x better for O_2, ~15x better for CO_2, and ~2.5x better for water than PET, leading to a longer shelf life of packaged products. PEF also offers higher mechanical strength, which means that thinner PEF packaging can be produced and fewer resources are required. In terms of thermal properties, PEF has superior ability to withstand heat and can be processed at lower temperatures. PEF has enhanced mechanical stiffness and allows for increasing shaping possibilities. More details on the PET vs. PEF comparison can be found in the nova-Institute supported report “PEF – A Sustainable Packaging Material for Bottles” (Puente et al., 2022).

Expected technological development (Annex 6, Technological Development, ID 8)

Although the main feedstocks, technologies and technical maturity (columns O, P and Q in the associated table) suggest that most are at a high technology readiness level (TRL 9), further, also significant, development can be anticipated through scaling up and incremental innovation. This evolution is essential for improving efficiency, reducing costs and increasing competitiveness compared to fossil-based alternatives. Key expected development pathways include:

- **Process optimisation through scaling**: As production volumes increase, established fermentation, chemical and enzymatic processes will become more efficient and cheaper. This mirrors innovation patterns in other clean technologies, where substantial learning and optimisation occur during the initial stages of commercial deployment.
- **Biological and technological advancements**: Incremental improvements in core technologies are expected. These include developing more efficient enzymes, engineered microorganisms (GMOs) and fermentation processes to increase yields. Furthermore, innovations in precision agriculture for feedstock and emerging electrochemical pathways (e.g. for drop-in chemicals) represent potential areas for efficiency breakthroughs.
- **Feedstock diversification and efficiency**: Technological development will also focus on expanding the feedstock base beyond first-generation sugars to include non-food biomass (e.g. lignocellulose and waste products) and even C1 gases (e.g. from industrial emissions). This will improve overall feedstock options as well as the circularity and resilience of biomass supply chains.

In summary, the primary technological trajectory for these polymers is not fundamental discovery, but rather systematic optimisation and scaling. This reduces the green premium, which is a known pattern in the bioeconomy where innovation continues well into the commercial phase to unlock the polymers' full economic and environmental benefits.

The technological development of the production processes of the respective polymers, including the technical maturity, main feedstock and technology used are shown in the columns O, P and Q in the table “Bio-based Polymers Worldwide” (see Excel Annex I). In the following the columns and their content are briefly described.

Column O – Technical Maturity

Shows how mature the technology for the production of the respective polymer currently is.

This classification indicates the current maturity of the core production technology for each polymer. For the commercially available polymers in scope, most technologies are already mature (TRL 9), and disruptive leaps are not the primary expectation. Instead, the most significant near-term advances are anticipated to come from.

- **Continuous Process Optimisation**: Incremental improvements in efficiency, yield, and cost, particularly through scaling, market competition and experience gains in established biological (e.g., fermentation) and chemical pathways.
- **Smart Technology Combinations**: The strategic integration of mature process steps to create new or optimized value chains.
- **Targeted Biological Advances**: In specific cases, such as for PHA, innovation may involve enhancing microbial strains to improve efficiency or tailor polymer properties.

While emerging pathways like electrochemistry hold long-term potential, their major impact is currently seen in the adjacent field of CO_2 utilisation rather than in displacing established bio-based polymer production routes.

Column P – Main Technology

Shows the currently used main technology for the production of the respective polymer. The majority of the polymers is produced by chemical polymerisation, although this process is highly individual for the individual polymer. Also, the building blocks used for the chemical polymerisation to synthesis the respective polymer can be obtained by fermentation. In the following the main technology for each of the respective polymers are described in detail in the following.

Aliphatic polycarbonates (APC) – cyclic and linear

Aliphatic polycarbonates (APC) can be synthesised by chemical polymerisation, specifically polycondensation of a diol and dimethyl carbonate, by ring-opening polymerisation of cyclic carbonate monomers or by copolymerisation of CO_2 with epoxides. The bio-based substitute in the APC is the diol. Dependent on the bio-based diol that is used for polycondensation with the dimethyl carbonate, the APC is classified as a drop-in, smart drop-in or dedicated polymer. For example, bio-based cyclic APC is produced by using isosorbide as the diol part classifying it as a dedicated polymer.

Casein polymers (CP)

Casein polymers (CP) are based on the milk protein casein and are produced from non-edible milk, not sufficient for human consumption, by extraction.

Cellulose acetate (CA)

Cellulose acetate (CA) is produced by reacting purified cellulose from sources like wood pulp or cotton linters with acetic anhydride in the presence of a catalyst, such as sulfuric acid. The resulting cellulose acetate can be partially hydrolysed to reduce the degree of acetylation (for example, to create cellulose diacetate), and then purified to remove byproducts. Finally, the CA is dried prior to further processing.

Epoxy resins

Epoxy resins are polyethers obtained by the chemical reaction of a compound comprising hydroxy groups as diols, polyols, phenolic compounds (e.g. bisphenol A) or diacids and epichlorohydrin. For the production of bio-based epoxy resins the current process is based on the use of bio-based epichlorohydrin (ECH) and a fossil-based hydroxy group compound, in the most cases bisphenol A (BPA).

Ethylene propylene diene monomer rubber (EPDM)

EPDM is produced by chemical polymerisation of ethylene, propylene and a diene. The bio-based part is coming from bio-based ethylene that is used for polymerisation.

Polyamides (PA)

Polyamides include aliphatic polyamides (e.g. polyamide 6 (PA 6) and polyamide 6,6 (PA 6,6)), polyphthalamides (semi aromatic polyamides; e.g. polyamide 6,T (PA 6,T)) and aramids (aromatic polyamides; e.g. Kevlar). Aliphatic polyamides are made through ring-opening-polymerisation of a lactam, like polyamide 6 (PA 6) from ε- caprolactam or from a diamine and a diacid, like 1,6-hexamethylene diamine and adipic acid for polyamide 6,6 (PA 6,6). A bio-based dedicated example for aliphatic polyamides is PA 6,12 made from fossil-based 1,6-hexamethylene diamine and bio-based sebacic acid from castor oil. Polyphthalamides, so semi aromatic polyamides are made from a diamine as 1,6- hexamethylene diamine and an aromatic acid as terephthalic acid resulting in for example polyamide 6,T (PA 6,T). A bio-based dedicated example for a polyphthalamides is PA 10,T made from bio-based 1,10-decamethylene diamine from castor oil and fossil-based terephthalic acid.

Poly(butylene adipate-co-terephthalate) (PBAT)

Poly(butylene adipate-co-terephthalate) (PBAT) is synthesised by chemical co-polymerisation of 1,4-butanediol (1,4-BDO), terephthalic acid (TPA) and adipic acid (AA). Currently, the bio-based part is coming from bio-based 1,4-butanediol (1,4-BDO) that is produced by fermentation from sugar (beet and cane) or starch (mainly from corn, wheat or cassava (in Asia).

Polybutylene succinate (PBS) and copolymers

Polybutylene succinate (PBS) and copolymers are synthesised by chemical co-polymerisation of 1,4-butanediol (1,4-BDO), succinic acid (SA) and regarding a copolymer adipic acid (AA) creating PBSA or terephthalic acid (TA) creating PBST. Currently, the bio-based part is coming from bio-based succinic acid (SA) that is produced by fermentation from sugar (beet and cane) or starch (mainly from corn, wheat or cassava (in Asia).

Polyethylene (PE)

Currently available polyethylene (PE) can be produced in two different ways resulting in either 30 % bio-based PE or 100 % bio-based PE. In general, PE is synthesised by polymerisation of its sole building block ethylene. Using bio-based naphtha (generated from used cooking oil (UCO)) as a feedstock for cracking to generate the ethylene results in 30 % bio-based PE. When using ethylene produced by dehydration of ethanol from sugarcane the resulting PE is 100 % bio-based.

Polyethylene furanoate (PEF)

The dedicated 100 % bio-based polymer polyethylene furanoate (PEF) is produced by chemical polymerisation of bio-based 2,5-furandicarboxylic acid (2,5-FDCA) and bio-based monoethylene glycol (MEG).

Polyethylene terephthalate (PET)

Bio-based polyethylene terephthalate (PET) is produced by chemical polymerisation of monoethylene glycol (MEG) and terephthalic acid (TA). Currently, the bio-based part is coming from bio-based monoethylene glycol (MEG).

Polyhydroxyalkanoates (PHA)

The 100 % bio-based, dedicated PHAs are found in nature, specifically PHB and a number of its copolymers like PHBV, PHBH, and P3HB4HB. These polymers are typically created in microorganisms, where PHA acts as carbon and energy storage material. Biotechnology has enabled to reproduce and optimise the enzymatically controlled biochemical conversion process of these microorganisms (fermentation) to favour PHA production yield and characteristics, while retaining the polymer structure as found in nature.

Polylactic acid (PLA)

The 100 % bio-based, dedicated polylactic acid (PLA) is produced by chemical polymerisation, specifically polycondensation of lactide acid or by ring-opening polymerisation of lactide. While the most common currently used technology is ring-opening polymerisation of lactide. The lactide is produced beforehand from lactic acid coming from fermentation of starch.

Polypropylene (PP)

In general, PP is synthesised by polymerisation of its sole building block propylene. Currently, PP is available with a 30 % bio-based content by using bio-based naphtha (generated from used cooking oil (UCO)) as a feedstock for cracking to generate the propylene. There are also future plans for new and increased 100 % PP production by fermentation of biomass to isopropanol which is then dehydrated to propylene or by using bio-based ethanol derived propylene.

Polytrimethylene terephthalate (PTT)

Polytrimethylene terephthalate (PTT) is a polyester synthesised by the polycondensation of 1,3-propanediol

(1,3-PDO) and terephthalic acid (TA). Currently, the bio-based part is coming from bio-based 1,3-propanediol (1,3-PDO).

Polyurethanes (PUR)

Based on the used components for polyurethane synthesis and the final degree of cross-linking polyurethanes are available as thermosets or as thermoplastic polyurethanes. In general, polyurethanes are synthesised by a polyaddition reaction from isocyanates and polyols, whereby both building blocks can be a wide range either of fossil-or bio-based linear, cyclic or aromatic isocyanates or a wide range from fossil- or bio-based polyols and bio-based natural oil polyols (NOPs).

Starch-containing polymer compounds (SCPC)

Starch as a natural and biodegradable polymer requires mild processing and manufacturing conditions compared to other polymers. Starch is not a good engineering polymer, but can be used as a low-cost filler with limited functionality – except its very good biodegradability in all environments. Therefore, usually additives or other polymers are added to make starch usable for material processing. In starch-containing polymer compounds thermoplastic materials, i.e. film products, the typical level of starch content does not exceed 30%, as starch is very hygroscopic and decreases the mechanical and barrier characteristics of a polymeric material. This means that the main component in such compounds are biodegradable (co-)polyesters (PBAT, PBS, PHA, PLA) or non-biodegradable polymers (PE, PP).

Column Q – Main Feedstock

Shows the main feedstock used for the production of the respective polymer via the main technology.

State of technological maturity / development of non-drop-in biobased plastic end-of-life management (Annex 6, Technological Development, ID 9)

The state of technological maturity / development of non-drop-in biobased plastic end-of-life management for recyclability and biodegradability is shown in columns S and T in the table “Bio-based Polymers Worldwide” (see Excel Annex I). In the following the columns and their content are briefly described.

Column R – Tonnes of Feedstock per Tonne of Polymer

Shows the tonnes of the respective feedstock that are needed to produce one tonne of polymer. The process pathways, feedstock needs from crop to feedstock (e.g. starch, sugar) and related land and water requirements are described in and taken from a detailed study by the German Institute for Bioplastics and Biocomposites, at Hochschule Hannover (IfBB, 2025). We have added one example in Annex II.

Column S – Recyclability

Shows the recyclability of the respective polymer.

Column T – Biodegradability

Shows if the respective polymer is biodegradable and in which environment. Details on these information and the mentioned testing conditions, standards and certifications can be found on the nova-Institute poster “Biodegradable Polymers in Various Environments According to Established Standards and Certification Schemes” (nova-Institute et al., 2024).

Environmental Performance

Climate Change impacts of biobased plastics (Annex 6, Elements related to the state of Environmental Performance, ID 1)

The production of bio-plastics is associated with GHG emission which cause climate change impacts. However, the bio-based feedstock which is used for production sequesters the carbon from the atmosphere which is later embedded in the polymer. That is an inherent advantage which can also be shown in GHG emission data and methodology. ISO 14067, EN 15804 and other standards apply the so called -1/+1 approach in the accounting of biogenic carbon. That means that the sequestered carbon is characterized with a -1 at the beginning of a product life cycle. The potential emission of the embedded carbon (through incineration or degradation) is considered equal as any other CO_2 emission (+1). This approach allows for showing the benefits of bio-based products in “Cradle-to-Gate” as well as “Cradle-to-Grave” system boundaries.

For this assessment, many sources have been reviewed. The following sources are considered highly relevant literature for environmental impacts of bio-based polymers:

- Beergsma et al., 2023
- Marson et al., 2023
- Nessi et al., 2020
- Plum et al., 2023
- Vanderreydt et al., 2021
- Vink & Davies, 2015
- Vural Gursel et al., 2021
- Walker & Rothman, 2020
- Zuiderveen et al., 2023

Comparable GHG emission data usually comes from comprehensive LCI (Life Cycle Inventory) databases, like ecoinvent or from individual LCAs. However, many bio-based polymers are relatively new in the market and not yet included in the data bases yet. Different studies are available on the Carbon Footprint of the bio-based materials which are in the scope, but not all bio-based polymers can be covered yet. We provide a list of values below in Table 6. Please consider that these data points stem from different sources and cannot be considered as methodolocially consistens and hence, comparable over the different lines.

Table 6: Exemplary Carbon Footprints of bio-based polymers (various sources)

Bio-based polymer	Process emission (Cradle to Gate)	Biogenic carbon uptake	Carbon Foorprint including BCU	Specific literature sources assessing the bio-based polymers
Polyethylene (PE)	1,28 kg	3 kg	-2,12* kg	LCA Study conducted by ACV Brasil/2023 (from cradle to Braskem factory gate); Adhering to ISO 14040, ISO 14044, and ISO 14071 standards, this LCA study was subject to a critical review process performed by KPMG. * includes a -0,4 kg CO2 eq for improved land.
Polyethylene furanoate (PEF)	3,0 kg	1,9 kg	1,1 kg	Final results from PEFerence project (grant agreement No 744409)
Polylactic acid (PLA)	3,1 kg	1,84 kg	1,26 kg	Ecoinvent 3.11 and Vink & Davies, 2015.

Polypropylene (PP)	0,6 kg	3,1 kg	-2,5 kg	Moretti et al., 2020, ecoinvent 3.11

The Carbon Footprints vary significantly between different polymers, potential feedstocks and applied methodology. Some polymers even become net-negative when including the biogenic carbon uptake. For clarity, we want to emphasise that a negative results do not necessarily mean that this is a carbon removal. Carbon removals require on the one hand a sequestration of carbon (which bio-based polymers in scope can deliver) but it also depends on a long use phase and EoL scenarios where the embedded carbon is not emitted again. Bio-based plastics can used in application that might qualify for this criterion (e.g., in building and construction), but this consideration out of scope of this study on material level.

The contribution of biobased plastics to climate change mitigation (Annex 6, Elements related to the state of Environmental Performance, ID 2)

This criterion adds the comparison with a fossil benchmark as we can assume substitution effects when using bio-based polymers and plastics. However, comparisons between different materials are complex as different material properties have to be taken into account (e.g. Marson et al., 2023). This is especially true for the new dedicated bio-based polymers, where no functionally equivalent benchmarks exist. For bio-PE, fossil PE can be taken as a benchmark. PEF, PLA or PHA have new and unique material properties which make a comparison only on material basis challenging. As mentioned, PEF is such a new material which can substitute PET in bottles and other applications. A peer-reviewed LCA shows that a considerable lower amount of PEF is needed to build a bottle than PET would require. A comparison per kg would be not fair as PEF has superior barrier properties. LCA standards require the so called Functional Unit to be equivalent between products that are compared. That is the function that the products can deliver – e.g. a bottle with 12 weeks shelf life, or a window that lasts 40 years. As this study stays only material polymer level, many comparisons are necessarily out of scope.

In addition, only few scientifically reliable source are available which offer quantititive comparisons between bio-based plastics and potential benchmarks. An exemplary list is shown below in Table 7.

Table 7: Climate Change impacts of bio-based polymers compared to conventional benchmarks per kg polymer (various sources)

Plastics	Benchmark	GWP Biobased	GWP fossil	Literature sources
Polyamides (PA)	Fossil PAs	1.3 kg	6.5 kg	ARKEMA – PA 11 (https://hpp.arkema.com/en/sustainability/life-cycle-assessment-carbon-foot-print/)
Polyethylene (PE)	Conventional PE	-2.12 kg	~2.3-3.5 kg	Braskem: LCA Study conducted by ACV Brasil/2023 (from cradle to Braskem factory gate); Adhering to ISO 14040, ISO 14044, and ISO 14071 standards, this LCA study was subject to a critical review process performed by KPMG. PE value from ecoinvent 3.10
Polyethylene furanoate (PEF)	PET	1.1 kg	~3.3-4.0 kg	Final results from PEFerence project ecoinvent 3.11. Puente & de Jong (2025).
Polypropylene (PP)	Fossil PP	-2.5 kg	~3 kg	Moretti et al., 2020, ecoinvent 3.11

For the studies that are cited in Table 7 short summaries are provided here to allow a more detailed picture.

The assessment covers biobased **PA11 (derived from the castor plant)**, including all “Amino 11” monomers and global Rilsan® PA11 production from Arkema. The scope is cradle-to-gate, meaning from raw material extraction (castor plant growth) to the “factory gate” — before transport to customers. The functional unit used for comparison is 1 kg of PA11. The production is described as “100% segregated bio-based PA11 production,” meaning the bio-origin content is fully tracked and separated from fossil-based feedstock. There is “no feedstock mass-balance allocation,” i.e. they don’t rely on mass-balance accounting that blends fossil and biobased feedstocks.

The reported carbon footprint is 1.3 kg CO_2e per kg of PA11. This value reflects improvements including the use of renewable energy (electricity and biomethane) and energy-efficient processes at production sites. Arkema follows recognized standards: ISO 14040, ISO 14044 and ISO 14067. For data, they combine primary data from their production sites with secondary data (e.g. upstream flows) from established LCA databases. The fossil benchmark is based on Arkemas fossil PA which ensure consistency in methodology and functional equivalency.

The LCA for **bio-based HDPE** follows a cradle-to-gate approach, covering all processes from sugarcane cultivation to polymer production at Braskem’s factory gate. It includes agricultural operations such as fertilizer application, harvesting, and sugarcane transport, as well as ethanol production and bio-ethylene synthesis. The study applies the Environmental Footprint 3.1 method in line with ISO 14040/44 and ISO 14071 (for review) standards, assessing 16 environmental impact categories (can be normalised and weighted to a single score). All results for HDPE are calculated per 1 kg of product, ensuring comparability with fossil HDPE. Biogenic carbon uptake is modelled theoretically based on the carbon content of ethylene, resulting in 3.14 kg CO_2 removed per kg of bio-based ethylene. This CO_2 removal is attributed to HDPE proportionally to the amount of bio-ethylene used in its production. The model assumes that biogenic carbon remains stored in the polymer until the factory gate because no degradation or incineration occurs before this stage. Downstream processes - conversion, use, and end-of-life - are excluded, meaning the study does not account for emissions or carbon release after the product leaves the plant. Fossil-based HDPE values are taken from ecoinvent global average datasets, ensuring consistency in comparison. The LCA was critically reviewed by third parties to confirm alignment of data, modelling assumptions, and methodology.

The LCA for PEF evaluates its environmental performance across cradle-to-gate boundaries, covering feedstock production, polymerisation, bottle manufacturing, and end-of-life. The system includes fructose production in Northwest Europe, FDCA synthesis via Avantium’s YXY Technology, and PEF polymerisation in Europe. Energy modelling reflects current Dutch electricity mixes and natural-gas-based steam, ensuring geographical consistency. Reference products are PET resin and PET bottles, enabling a direct comparison with the dominant fossil-based alternative. The assessment applies the EF 3.1 method to the full set of environmental indicators, including climate change, resource use, land use, toxicity, and eutrophication. Data quality is high, combining primary industrial datasets with secondary sources such as Agribalyse, Ecoinvent, and Eunomia, with full validation by three independent reviewers.

The study performs a cradle-to-factory-gate life cycle assessment (LCA) of **polypropylene (PP) produced from used cooking oil (UCO)**, comparing it to conventional petrochemical PP. It evaluates 16 environmental impact categories. For processes that yield multiple outputs (i.e. multiproduct systems), the authors test several allocation methods, rather than assuming a single default approach - explicitly investigating how different allocation choices influence the results. The analysis includes normalization and weighting steps to derive an overall environmental performance profile, not just raw impact scores. According to their findings, the main contributors ("hotspots") to impacts for UCO-based PP are the polymerization process, hydrogen production, LPG production, and combustion of LPG, reflecting that downstream processing dominates environmental burdens. Compared with fossil PP, the UCO-based PP achieves a 40 - 62% reduction in climate-change impact and an 80 - 86% reduction in fossil resource use, depending on the allocation method applied. However, for many of the other 13 impact categories, the environmental benefit is highly sensitive to the allocation method chosen, meaning results can vary substantially.

For other biobased polymers, carbon footprints are much more difficult to find, and often not straightforward to rely upon due to low-TRL stages, different scopes, etc. Some examples include carbon footprint results for bio-based PBAT ("37% lower carbon footprint than fossil-based" (Luo et al., 2025), bio-based PBS ("*1G fully bio-based PBS plastic products were found to have comparable environmental impacts than their petrochemical incumbents, while 2G fully biobased PBS plastic products allow to reduce NREU and GHG by around one third under the condition of avoidance of concentration of sugars and energy integration of the pre-treatment process with monomer production*" (Patel et al., 2018), bio-based PHA ("*The global warming potential (GWP) of a PHA production using sugarcane ranged from 0.86 to 1.59 kg CO_2 equiv/kg aPHA, while that of corn grains ranged from 0.01 to 1.96 kg CO_2 equiv/kg aPHA. Thus, in terms of its environmental impact, the findings suggest that a PHA, as a biobased and biodegradable plastic, shows improved performance compared to fossil fuel-based plastics." (Lee et al., 2023)*, but different studies can lead to different results and outcomes.

There are other studies available which compare bio-based and fossil polymers and products on a higher level. Quotations from main studies that relate to GHG emissions are provided below:

- *"Overall, studies discussed in this review article show that the harms associated with bioplastics are less severe as compared to conventional plastics."* (Atiwesh et al., 2021)
- *"Compared with fossil-based plastics, bio-based plastics can have a lower carbon footprint and exhibit advantageous materials properties;"* (Rosenboom et al., 2022)
- *"The reviewed literature suggests that one metric ton (t) of biobased materials saves, relative to conventional materials, 55 ± 34 gigajoules of primary energy and 3 ± 1 t carbon dioxide equivalents of greenhouse gases."* (Weiss et al., 2012)

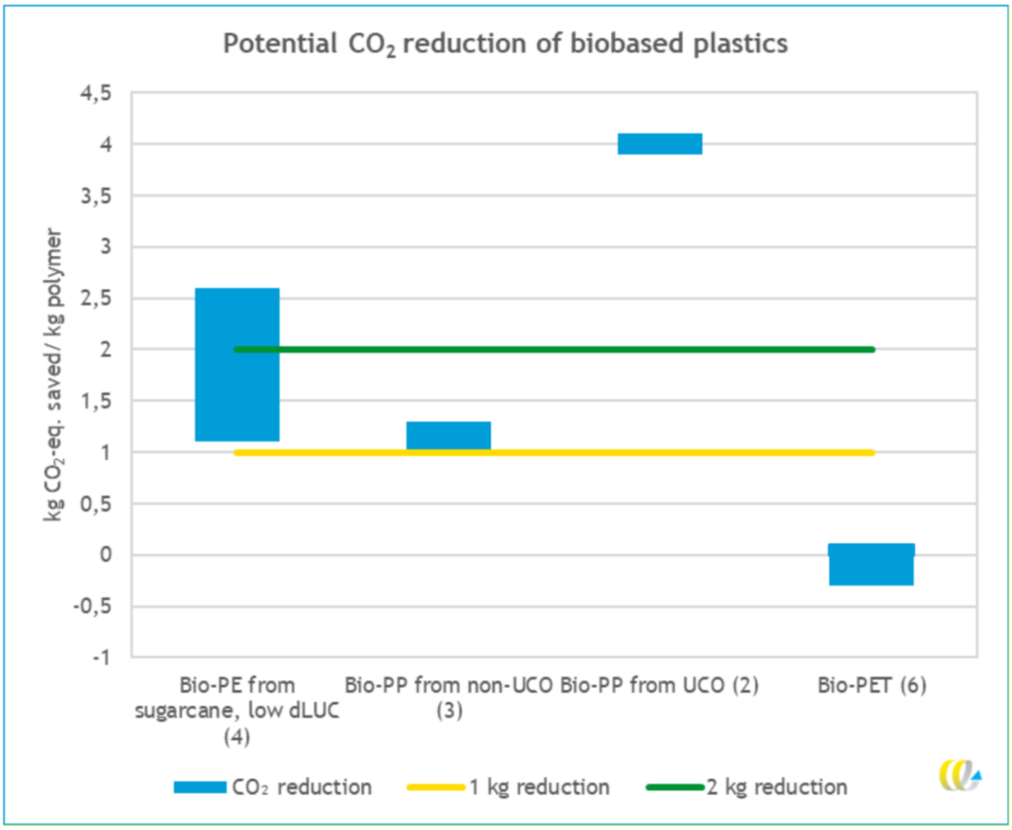

Figure 9: Potential CO_2 reduction of selected bio-based materials (source: Beergsma et al. 2023)

A CE Delft study analysed existing GHG mitigation data for four types of bio-based plastics, namely bio-PE, two types of bio-based PP and bio-based PET. For three out of four plastics, a significant mitigation potential can be observed. Only for bio-based PET, the carbon footprints are comparable. The results are shown in Figure 9.

Zuiderveen et al (2023) have summarised studies the environmental impacts of bio-based products, including bio-based polymers in comparison with respective benchmarks. Figure 10 shows that GHG emissions are in general lower for bio-based polymers to compared to conventional benchmarks.

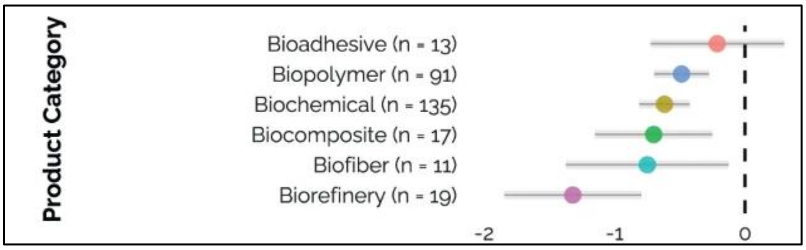

Figure 10: Change in GHG footprint response ratios (RR) in relation to key parameters (adapted from Zuideveen et al, 2023)

Finally, recent updates of LCI databases visualise previously underestimated methane emissions from fossil feedstocks – which were identified through enhanced satellite data – with major implications for comparing the carbon footprints of fossil-based versus renewable carbon chemicals and materials. The revisions reveal stark inconsistencies in emission reporting across industry sources like the International Energy Agency (IEA) or International Association of Oil & Gas Producers (IOGP). For example, global methane emissions from oil production are now reported to be 15 times higher in International Energy Agency (IEA) data compared to IOGP figures, with discrepancies for Russia reaching 10-fold and for Saudi Arabia an astonishing 40-fold.

These data revisions mean that the carbon footprint of key fossil-based feedstocks and downstream products, as tracked in such LCI databases, has risen sharply over the past years (see Figure 11 and Figure 12. For instance, the climate impact attributed to naphtha – the most common olefin feedstock – has almost increased twofold due to methane emissions.

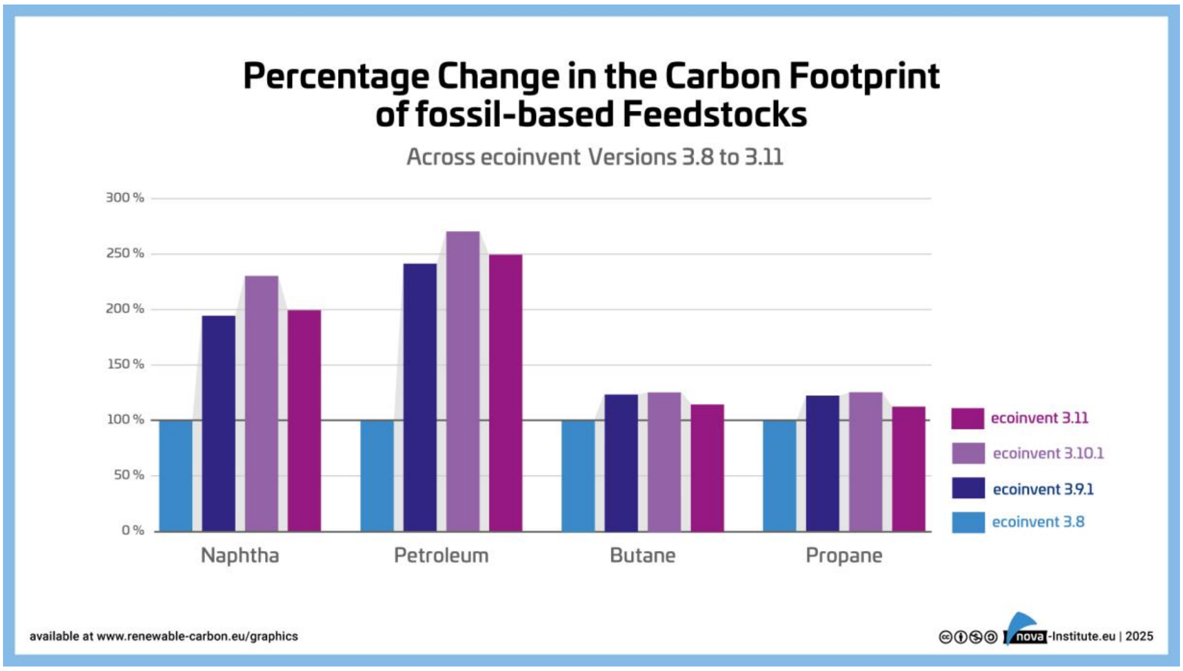

Figure 11: Percentage Change in the Carbon Footprint of fossil-based feedstocks between ecoinvent 3.8 (2021) and 3.11 (2024).

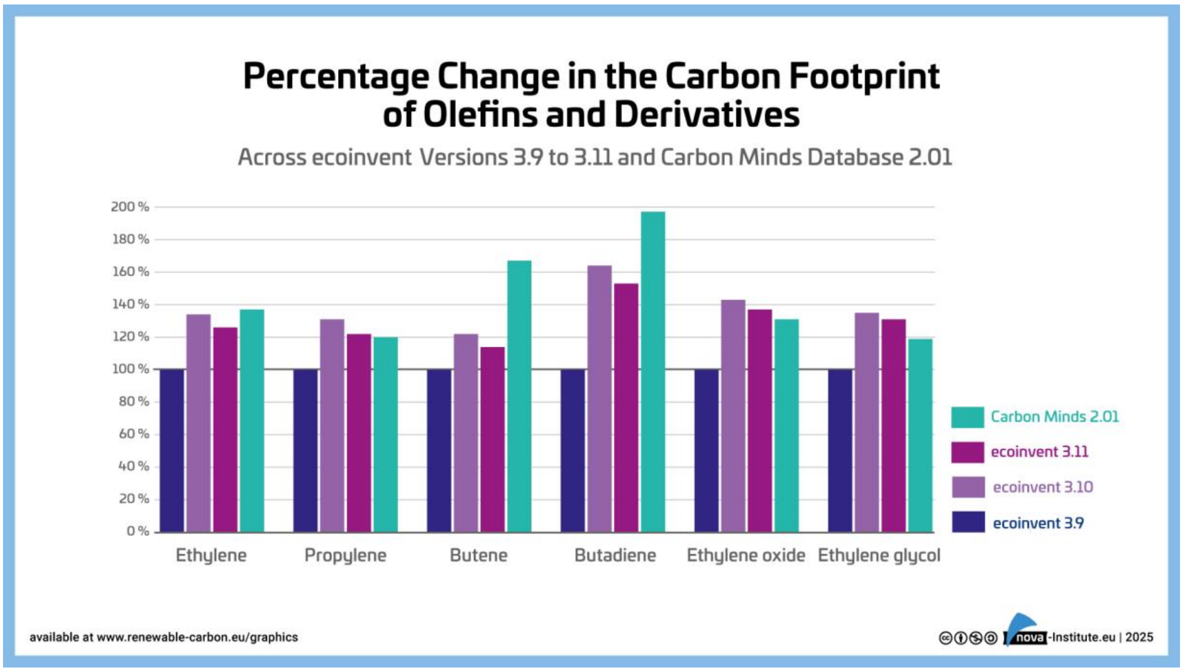

Figure 12: Percentage Change in the Carbon Footprint of Olefines and Derivates between ecoinvent 3.9 (2022) and 3.11 (2024)

Other environmental impacts of bio-based plastic considering a life cycle approach, considering the other impact categories beyond Climate Change, such as those of the Environmental Footprint method (Annex 6, Elements related to the state of Environmental Performance, ID 3)

Environmental impacts are more than only the impacts on global warming. Recent Impact Assessment models like the Environmental Footprint method include also many different other aspects like Eutrophication, acidification, toxicity, resource uses or ozone depletion. Please find the full list of impacts in Figure 13.

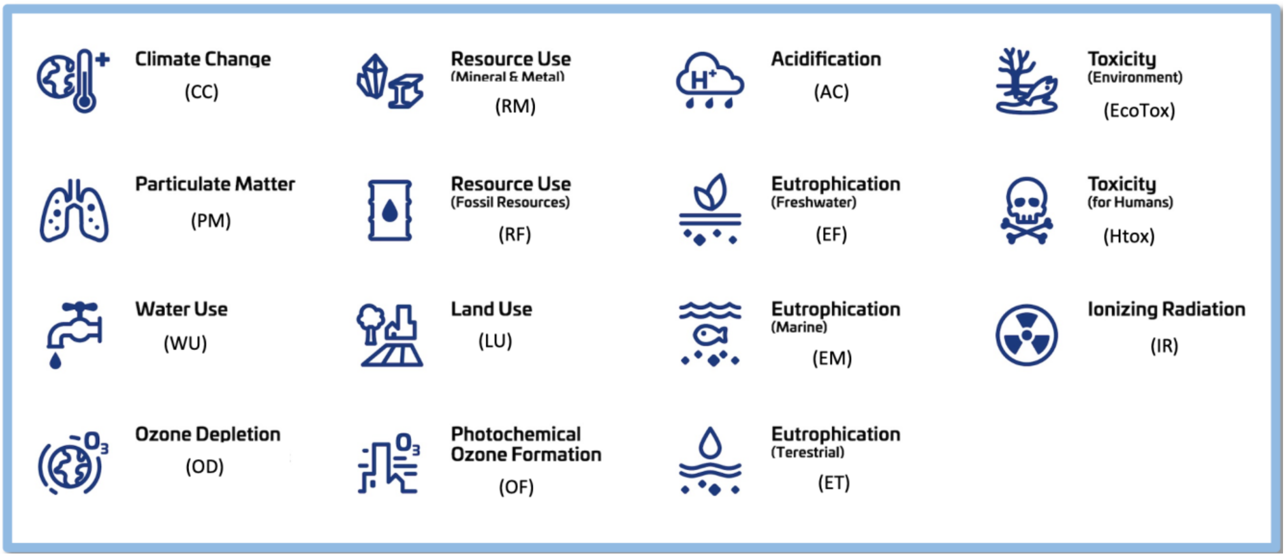

Figure 13: Environmental impacts that are included in EF 3.1 model (visualisation from nova-Institut GmbH)

Zuiderveen et al (2023) have also analysed some more impact categories that go beyond Climate Change. Figure 14 shows the results of the study. It shows a clear trend that for the comparison of bio-based products to fossil benchmarks, environmental impacts via GHG emissions, non-renewable energy use, ozone depletion and photochemical ozone formation is either less or somehow equal, while the land-use related impacts of eutrophication and acidification impacts are higher.

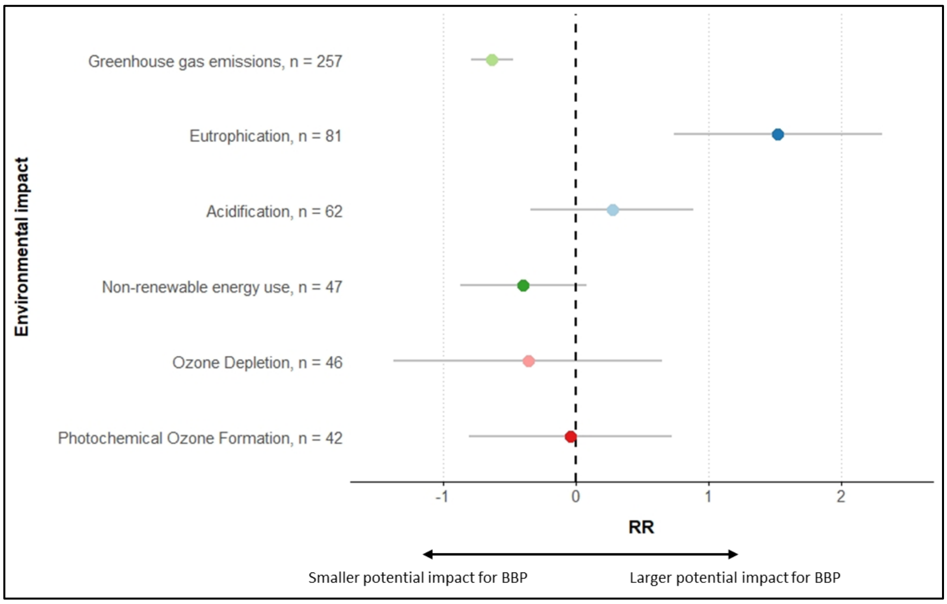

Figure 14: Environmental impacts of bio-based products compared to fossil benchmarks (Zuiderveen et al., 2023)

Also other studies emphazise higher impacts in different categories or life cycle stages:

- *“However, these benefits can have trade-offs, including negative agricultural impacts […]”* (Rosenboom et al., 2022)
- *“Biobased materials may exert higher environmental impacts than their conventional counterparts in the categories of eutrophication and stratospheric ozone depletion; our results are inconclusive with regard to acidification and photochemical ozone formation.”* (Weiss et al., 2012)

Higher results for the impact categories that typically belong to agricultural activities are not suprising when comparing an agriculture-based product with a value chain which has not any agricultural activity at all.

However, it is important to judge whether an impact is relevant at all. A hundred times multiplied with almost nothing is still almost nothing. Having only relative results can be highly misleading. In LCA, normalization can help to interpret the absolut significance of impacts. In the step of normalization, the impacts are compared to e.g., overall impacts in that category per capita. The Environmental Footprint methodology (EF 3.1) offers such a normalisation framework. In the PEFerence project, a peer reviewed LCA on a PEF bottle compared to a conventional PET bottle was conducted. Characterized results were also normalized and wheighted following the EF 3.1 factors to judge the relevance of different impact categories.

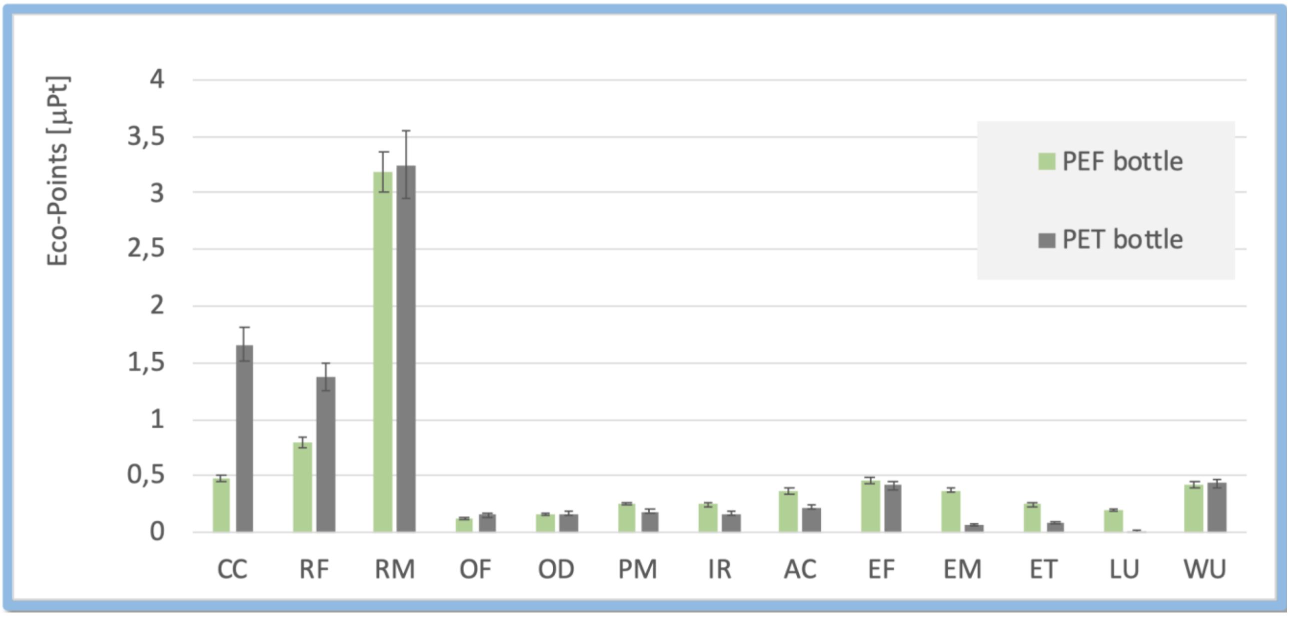

Figure 15: Normalised & Weighted Impacts of PEF and PET bottles (final results of PEFerence project)

Figure 15 shows normalized and wheighted results following most recent EF 3.1 methodology. It can be seen that the bio-based PEF scores worse than fossil based PET in some impact categories, like acidification (AC), eutrophication marine and terrestrial (EM and ET) and well as for Land Use (LU). However, the analysis shows also that the impact categories where PEF is clearly having a lower impact (Climate Change (CC) and Resource use, fossil (RF)) are overall much more relevant on a normalised scale. This result is only one study and cannot be generalised, but it shall show one limitation of relative results and their comparisons.

Highlights on the effect of bio-based plastic on soil health, land use change and biodiversity (Annex 6, Elements related to the state of Environmental Performance, ID 4)

Assessing soil health, land-use change (LUC), and biodiversity at the level of a generic bio-based polymer is fundamentally challenged by high variability in agricultural practices and regional contexts. Consequently, environmental claims can only be made for specific value chains, not for the polymer itself. This mirrors the approach of the Renewable Energy Directive (RED), which sets sustainability criteria at the feedstock and farm level rather than requiring generic product-level indicators.

Soil health is an emerging priority which needs to be addressed, but its assessment is highly dependent on local agricultural practices. Every bio-based can be produced from biomass which stems from well managed soils as well as from not so well managed ones. This variety is true for all bio- (or land-) based plastics as well as for all other bio-based products, including food, feed or fuels. Therefore, influencing soil health requires action at the farm level, where management decisions are made, not at the polymer level. In the end, LCAs shall help to identify that bio-based products ensure soil health, but the variation in results itself is a reason to highlight that single numbers without deeper interpretation will not provide a feasible baseline for decision-making.

Land-Use Change is often intuitively connected to deforestation or making arable land from peatland and, unfortunately, this is also often true for some feedstocks in some regions of the world. All products that stem from land-based production systems have certain risk of causing Land Use Change. However, impacts to climate change from LUC are already accounted for in the GHG emission values of bio-based polymers by depreciation of the loss in carbon stock over 20 years.

An important aspect is also that LUC is not inherently negative, and can also be positive. Guarengui et al. (2023) report that the cultivation of sugar cane in parts of Brazil can be considered as carbon sink as different measures have led to higher carbon stock in land compared to 20 years ago. The bio-based PE from BRASKEM uses this feedstocks and receives a credit for that in their peer reviewed LCA.

Biodiversity is an important aspect, but difficult to measure due to still ongoing methodological development and again intensely local differences. This means that such impacts have limited value to quantify biodiversity impacts on a generic polymer level. Figure 16 shows different approaches and methodological development of the recent years. BioMAPS and GLAM seem to be promising candidates for future inclusion into environmental assessment frameworks. However, both methods are still in the development and testing phase.

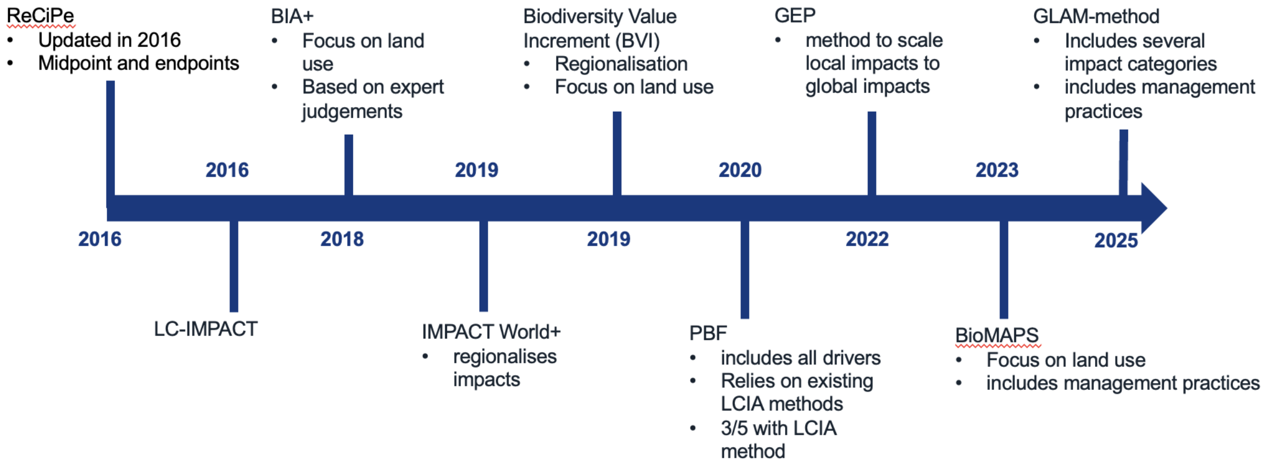

Figure 16: Most recent approaches to assess biodiversity in LCA (source: nova-Institut GmbH)

The ReCiPe method is theoretically and practically applicable, but has obviously not yet been able to gain wider acceptance so far. It follows the concept of so called endpoint indicators, which model not only impacts but damages. The model offers “Damage to ecosystem” which is caused by “Damage to freshwater species”, “Damage to terrestrial species” and “Damage to marine species”. This could be taken as a proxy indicator for “biodiversity”.

Figure 17 shows the impact that potentially cause the damage to ecosystems: Global Warming, Water Use, Land Use and Transformation, Eco-toxicity and acidification. Building on the previous chapters, bio-based plastics usually cause less impacts to climate change than fossil ones which causes also less damage to ecosystems. However, more land use, more eutrophication and potentially more acidification might have reverse effects. Full quantification which is broadly accepted and recognized is not possible, yet.

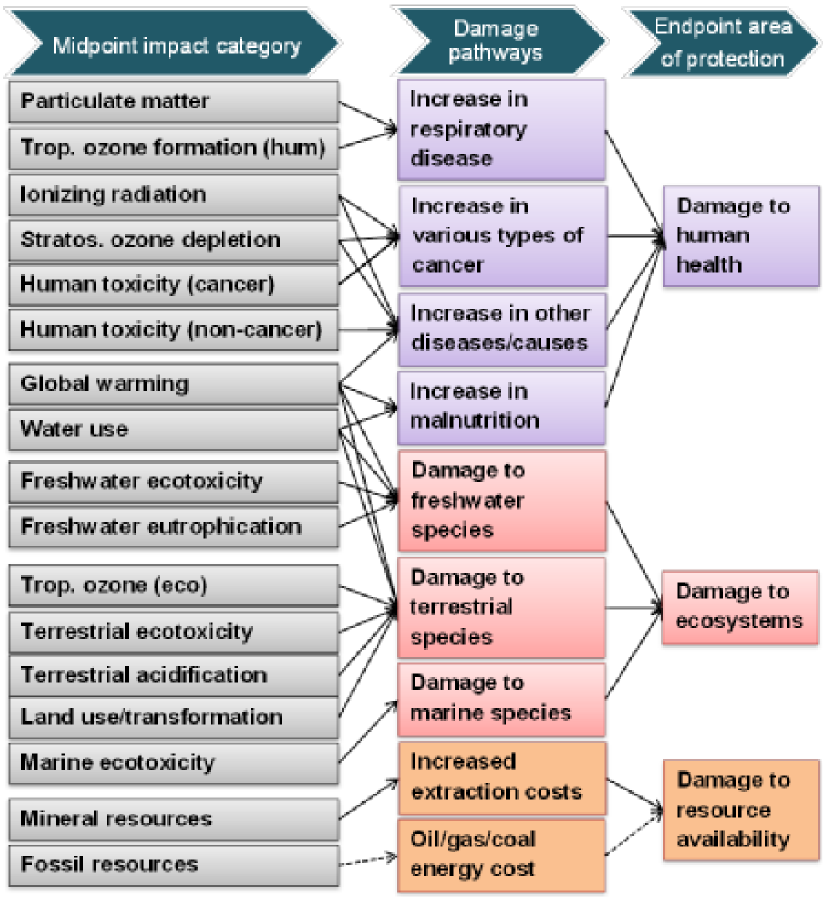

Figure 17: Cause effect relationships in ReCiPe 2016 model (RIVM Netherlands)

One important aspect of biodiversity is that different actions and impacts can be locally very different. That is the reason why newer methods like BioMAPS put a strong emphasis on land use (change) and where this land is located. Models like ReCiPe which just translate aggregated impacts, cannot cover this aspect adequately.

All in all, biodiversity cannot be assessed yet on polymer level using a recommend or broadly accepted methodology. It is also very much feedstock-dependent and supplier specific and cannot be generalized on a generic product level. Biofuels use very similar feedstocks and have the same requirements in keeping harm to biodiversity low. The Renewable Energy Directive does not require quantification of a certain biodiversity indicator, but provides criteria for biomass that is allowed to be used for the production. Different certification schemes have adopted these criteria and can show feedstock- and supplier-specific that safeguards are met to protect biodiversity. This could also be a way forward to address biodiversity in bio-based polymers and will be further discussed in the next criterion which is specifically on RED sustainability criteria.

Status of the BBP value chain regarding potential compliance with RED sustainability criteria (Annex 6, Elements related to the state of Environmental Performance, ID 5)

The Renewable Energy Directive (Directive (EU 2018/2001) and Directive (EU 2023/2413) provides in Article 29 different criteria for feedstocks to be used in eligible bio-based fuels. Summarised, these are:

- Land-use criteria
  Raw materials cannot be sourced from land with:
  - High biodiversity value (primary forests, nature reserves, protected habitats).
  - High carbon stock (wetlands, peatlands, continuously forested areas).
  - Recently deforested or converted lands
  - Agricultural biomass must respect the Common Agricultural Policy (CAP) environmental requirements.
- Forest biomass criteria
  - Must come from legally harvested wood and sustainably managed forests.
  - Member States or voluntary certification schemes must ensure:
  - Forest regeneration after harvest.
  - Maintenance of biodiversity, soil quality, and long-term carbon stocks.
  - Monitoring and enforcement in the country of origin.
- The amended version ("RED III") has proposed even stricter rules especially for forest biomass.

All bio-based polymers on the list can technically comply with these criteria. There is no technical or chemical reason why that should be a limitation. For instance, commercial bio-based polyethylene (PE) derived from sustainably cultivated sugarcane – as in the case of BRASKEM's I'm green™ product – demonstrates that compliant value chains are already operational. The main reason why biofuels proof compliance and bio-based polymers usually do not, is the existing regulatory framework which creates a business case for bio-based fuels that incentivises compliance. This does not exist for bio-based polymers. The criteria predominantly address agricultural and forestry practices, traceability, and land management, not the technical production pathway or chemical structure of the final polymer. Therefore, there is no inherent technical or chemical property of bio-based plastics that prevents the use of RED-compliant feedstocks. For fuels, quotas and funding are in place which create a market where specific sourcing criteria can be met and where the monetary costs for certification can be passed through. For bio-based polymers, no funding or quotas exist and comprehensive certification of feedstock adds additional monetary burdens which are difficult to affort.

The Renewable Carbon Initiative (RCI, 2025) has developed a position on sustainability criteria for biomass, informed by dialogue with the European Commission. It concludes that the sustainability criteria established under the Renewable Energy Directive (RED) provide a robust foundational framework for biomass used in bio-based polymers. This assessment holds particularly true for agricultural biomass. For forestry biomass, stakeholders have indicated that certain adaptations to the RED criteria are necessary to ensure alignment with other regulations and to facilitate their effective application.

The position jointly agreed on the follow sustainability aspects being key for valid sustainability criteria: sustainable cultivation of biomass, net greenhouse gas emission reductions along the life-cycle, and eligibility of different types of feedstocks. A key conclusion is that **sustainability criteria are most effective when coupled with market incentives**, such as quotas for compliance or penalties for non-compliance.

Substantial work within RCI has focused on operationalising these principles, resulting in a detailed overview (Table 8) that assesses the practical implementability of RED sustainability criteria for bio-based chemicals and derived materials.

Key:

- ❌ not applicable to bio-based chemicals and derived materials;
- ✅ applicable to bio-based chemicals and derived materials;
- ☑️ applicable to bio-based chemicals and derived materials with modifications.

Table 8: RED Art 29 sustainability criteria for biomass for bioenergy purposes and main content classified according to their implementability for bio-based chemicals and derived materials.

Aspect in RED	Main content	RED III Clause	Implementable for bio-based chemicals and materials from agricultural biomass	Implementable for bio-based chemicals and materials from forest biomass
Definitions	Defining biomass linked terminology used in criteria	Art. 2	✅	✅
Scope of criteria	Linking criteria to regulatory targets, scoping applicable criteria for different biomass	Art. 29 (1)	☑️	☑️
Protecting soil carbon	Impacts on soil carbon must to be monitored and managed when sourcing agricultural waste and residues	Art. 29 (2)	✅	✅
Protecting biodiversity	Biomass cannot be obtained from land with high biodiversity value (or had such value in 2008 regardless of whether that remains)	Art. 29 (3)	✅	☑️
Maintaining land carbon stocks	Biomass cannot be obtained from land that previously had high carbon stocks (e.g. change from natural forest to farmland after 2008 banned)	Art. 29 (4)	✅	☑️ *
Protecting peatlands	Biomass cannot be obtained from land that was peatland (e.g. draining soil and conversion from peatland to farmland after 2008 banned)	Art. 29 (5)	✅	✅
Ensuring sustainable forest management	Ensuring sustainable forest management (e.g. legality, regeneration, preservation of habitats)	Art. 29 (6)	n/a	✅
LULUCF criteria	LULUCF criteria applied to production from forest biomass	Art. 29 (7)	n/a	❌ *
Implementing acts and revision	Requirement for EC to set implementing acts by 2021 and review of criteria by 2026	Art. 29 (8-9)	❌	n/a
Greenhouse gas emission savings	Criteria to reach minimum percentage of emission savings compared to fossil fuels	Art. 29 (10)	☑️	☑️ *

Efficient use of electricity from biomass	Requirements for electricity producing sites for eligibility	Art. 29 (11)	✗	n/a
Harmonisation of criteria across member states	Requirements for member states to accept compliance for biofuels and bioliquids fulfilling the criteria	Art. 29 (12)	✓	✓
Derogations from the criteria		Art. 29 (13-15)	✗	✗
Certification and verification of compliance		Art. 30	✓	✓

The status of biodegradability, and compostability of bio-based plastics (Annex 6, Environmental Performance, ID 6)

Establishing clear, scientifically sound environmental criteria for the biodegradability of bio-based plastics is a feasible and necessary policy objective. Robust standards and certification frameworks already exist, providing a solid foundation for verification and trust, which can be integrated into regulations to create market clarity and support the bioeconomy (European Bioplastics, 2025). The primary challenge is not a lack of scientific criteria but ensuring proper waste management infrastructure and consumer awareness (Mhaddolkar et al., 2025). This is a system-level issue common to all new material flows and can be addressed through parallel policy measures, such as infrastructure investment and clear labeling laws. Setting clear product criteria is, in fact, the essential first step that guides these downstream investments.

The status of biodegradability, and compostability of bio-based plastics is shown in the column T in the table "Bio-based Polymers Worldwide" (see Excel Annex I). In the following the columns and their content are briefly described.

Column T – Biodegradability

Shows the if the respective polymer is biodegradable and in which environment. Details on these information and the mentioned testing conditions, standards and certifications can be found on the nova-Institute poster "Biodegradable Polymers in Various Environments According to Established Standards and Certification Schemes" (Figure 18) (nova-Institute et al., 2024).

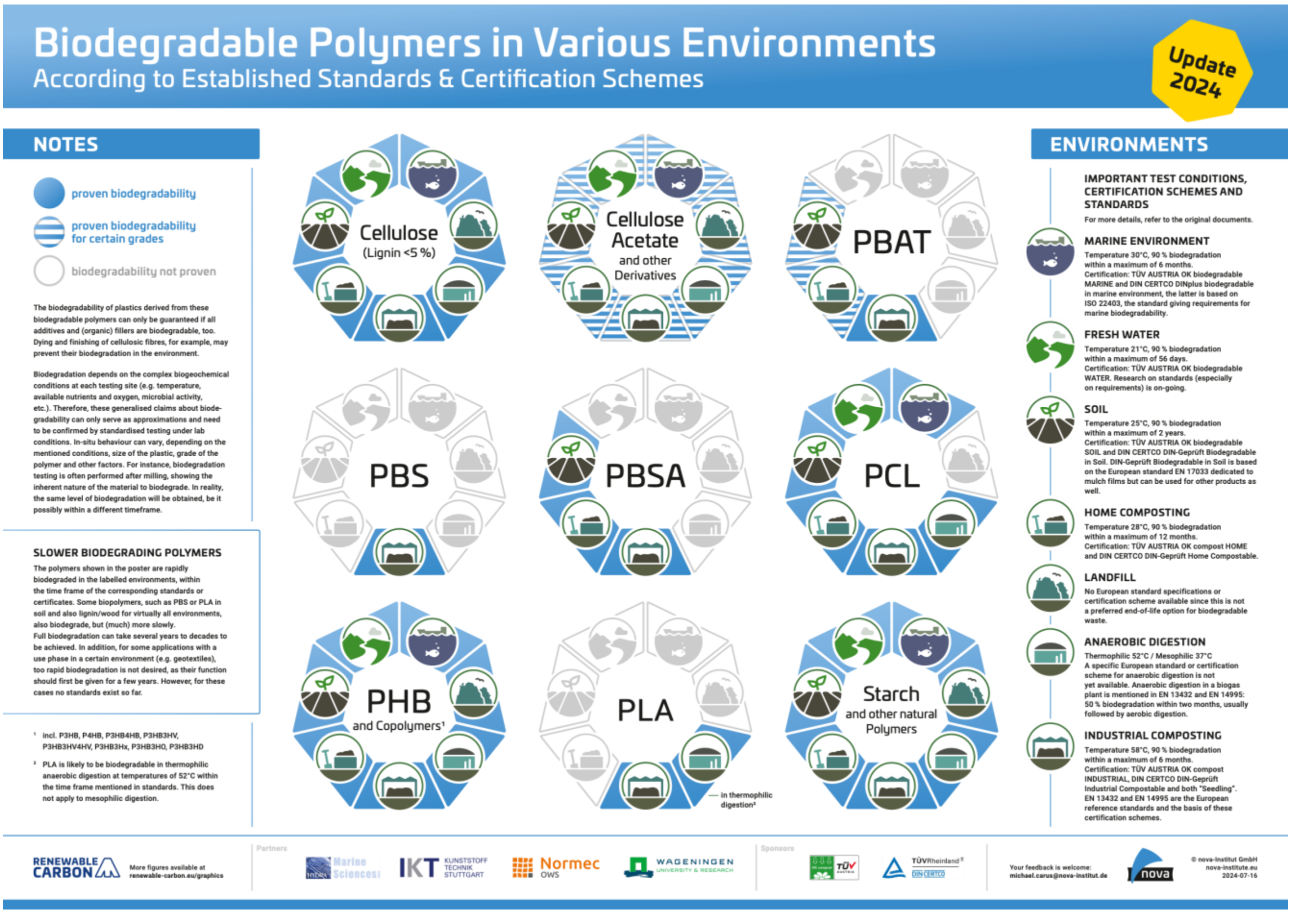

Figure 18: Third update of the poster showing biodegradable polymers in different environments according to established standards and certification schemes.

The status of recyclability of bio-based plastics (Annex 6, Environmental Performance, ID 7)

Bio-based plastics demonstrate varied recyclability potential, with drop-in thermoplastics achieving seamless integration into existing streams while novel bio-based polymers face infrastructure challenges. All bio-based thermoplastics, the largest share of bio-based plastics produced today, can be collected, separated from other plastics (with modern equipment) an mechanically recycled. Also different kinds of chemical recycling work well (see below). Though post-consumer recycling depends on sufficient commercial volumes and market demand which justifies the economic investment in collection separation infrastructure.

Recyclability rates and polymer-specific data reveal significant differences across material types. Drop-in bio-based plastics – chemically and physically identical to fossil counterparts including bio-based PE, bio-based PET, bio-based PBAT and bio-based PP – can be recycled in well-established streams alongside conventional equivalents and the recycling share are roughly the same as for the fossil counterparts.

On a side-note: Most fossil- and also bio-based polymers are "thermoplastics", which are defined as a class of polymers that become soft and moldable when heated, and harden again when cooled. This allows them to be reshaped multiple times without significant chemical changes. All of these can be mechanically recycled. This is in contrast to 'thermosets', a class of polymers that harden irreversibly during a chemical process to form a rigid, three-dimensional network of cross-linked molecules. Once cured, thermosets cannot be softened or remelted by heat. This means they cannot be mechanically recycled, but can only be used as a filler or chemically recycled. Epoxy resins and polyurethanes (PUR) are the only thermosets in the list of 17 bio-based polymers.

Novel bio-based polymers face greater challenges. PLA and PEF can be mechanically recycled but require separation from other plastics in waste streams – technically feasible with NIR sorting technologies used throughout the EU, for example by the Green Dot (Grüner Punkt). PLA can be identified with 98% accuracy using NIR scanners. However, commercial-scale PLA recycling infrastructure remains limited, with expectations that separate recycling streams will become feasible in the short to medium term as volumes increase. PHA exhibits instability at high temperatures, complicating mechanical recycling, though PHB-PLA blends demonstrate improved recyclability (11 cycles) compared to individual performance (PHB: 3 cycles, PLA: 10 cycles). Chemical recycling via hydrolysis represents a promising depolymerization method for PLA to the monomere lactic acid. Even selective depolymerization from PLA-PET mixed waste was demonstrated using zinc acetate catalysts.

Integration into existing waste management systems depends critically on sorting accuracy and infrastructure compatibility. Efficient polymer-specific sorting can be performed with existing NIR equipment at sorting/recycling facilities when appropriate spectra libraries for bioplastics are utilized. Trials by TOMRA and SEALIVE demonstrated NIR technology correctly sorts biodegradable plastics with error rates below contamination thresholds, with PLA not interfering with PET streams when detection settings are properly configured. Dynamic sorting tests in Italy, the Netherlands, and Spain showed consistent accuracy processing both rigid and flexible bioplastics simultaneously.

The status of recyclability of bio-based plastics is shown in the column Q in the table “Bio-based Polymers Worldwide” (see Excel file). In the following the columns and their content are briefly described.

Industrial and home composting as well as all kind of biodegradation can also be recognized as biological recycling, keeping the bio-based plastics molecules in the biological cycle. This can work for about half of all bio-based plastics, the biodegradable plastics (PLA, PHA/PHBs, PBS, PBAT … see Figure 18) whereas the other half is not biodegradable.

Column S – Recyclability

Shows the recyclability of the respective polymer.

The end-of-life collection rate of biobased plastic waste (Annex 6, Environmental Performance, ID 8)

End-of-life collection rates for bio-based plastics remain poorly documented compared to conventional plastics, with available data suggesting low and heterogeneous collection across European Member States. The fundamental challenge stems from bio-based plastics' distribution across multiple waste streams and lack of dedicated collection infrastructure specifically designed for these materials. This is of course also due to the fact that bio-based plastics only make up ~1% of all plastics, and that recycling rates in general come with significant uncertainties.

Collection rate data for bio-based plastics specifically is scarce. Overall post-consumer plastics waste collection in the EU27+3 reached 29.5 million tonnes in 2020 (Plastics Europe, 2022) and 32.3 million tonnes in 2022 (Plastics Europe 2024), representing conventional plastics predominantly. Bioplastics production in 2024 reached approximately 1.44 million tonnes actual production versus 2.47 million tonnes capacity (58% utilization rate), though end-of-life collection statistics for these materials are not systematically tracked separately from conventional plastics. The lack of material-specific tracking creates significant data gaps preventing accurate assessment of bio-based plastic collection performance.

Two recent reports give a comprehensive and detailed overview on recycling in Europe and global plastics flows with data on collection and also end-of life for different regions (Globe Newswire 2025 and Houssini et al., 2025, e.g. Figure 20). The Chinese Study shows a 2% feedstock share for bio-based plastics (Figure 19) (Houssini et al., 2025), instead about 1% in the nova Biopolymer-Report.

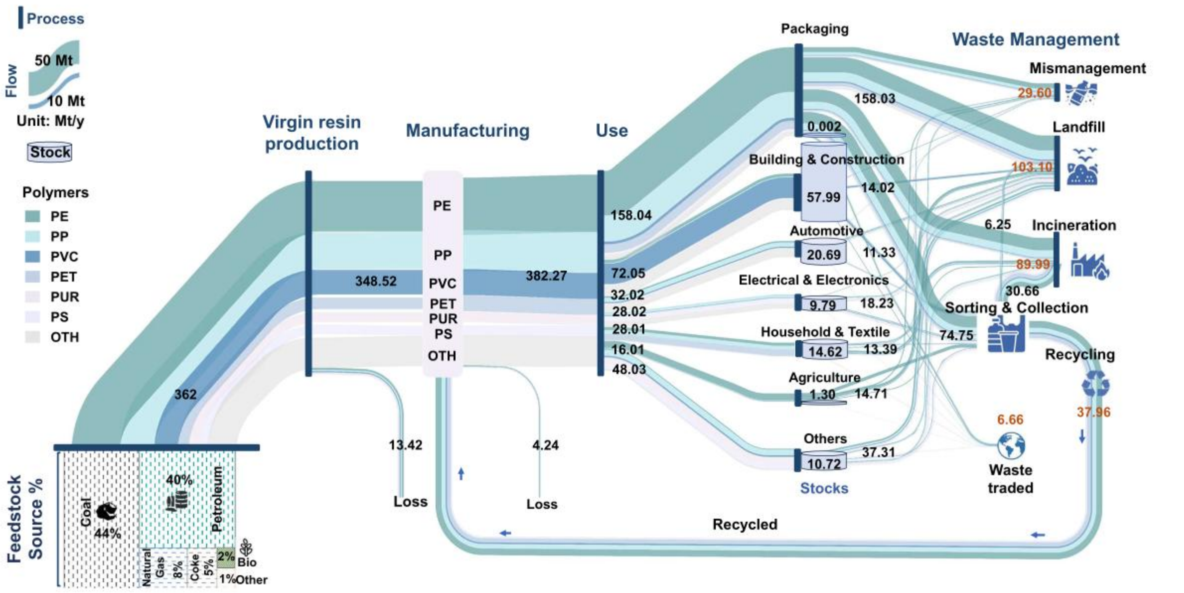

Fig. 1 | Global plastic cycles in 2022. The global plastics cycles are illustrated by flows. Color and width of flows correspond to the types and mass of plastics, respectively. All units in Mt/y. *Note: minor discrepancies in values are due to rounding during mass balance calculations.*

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Figure 19: Global plastic cycles in 2022 (Houssini et al., 2025). The global plastics cycles are illustrated by flows. Color and width of flows correspond to the types and mass of plastics, respectively. All units in Mt/y. Note: minor discrepancies in values are due to rounding

https://doi.org/10.1038/s43247-025-02169-5 **Article**

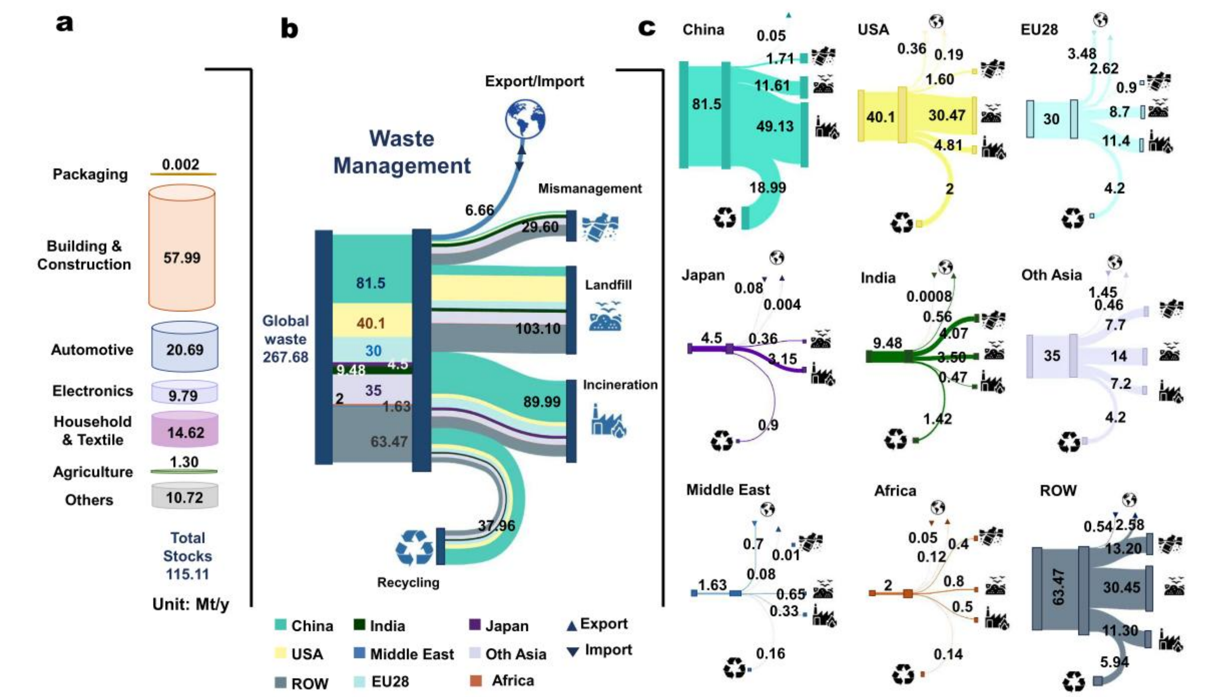

Fig. 4 | Global plastics waste generated. **a** Global plastics stocks per industrial sector. **b** Global waste management and end-of-life waste, breakdown per country/region. **c** Regional and national plastics waste management. Color and width of flows correspond to the countries and mass of plastic waste, respectively. All units in Mt/y units. *Note: minor discrepancies in values are due to rounding during mass balance calculations.*

Figure 20: Global plastics waste generated a) Global plastics stocks per industrial sector. b) Global waste management and end-of-life waste, breakdown per country/region. c) Regional and national plastics waste management. (Houssini et al., 2025)

Where data exists for specific material streams, collection effectiveness varies dramatically. In Italy, where compostable packaging collection is well-established, the Biorepack EPR system reports a 56.9% recycling rate of industrially compostable packaging placed on the market in 2023 (Biorepack, 2024). This represents one of the highest documented collection rates for bio-based biodegradable plastics globally. However, Italy's performance is exceptional; most European countries lack comparable systems. In countries with restrictive policies on compostable plastics (Germany, Belgium, Netherlands), collection rates for bio-waste remain low at 15-25% despite mandatory separate collection, indirectly affecting compostable plastic collection, based on Eurostat[1].

Polymer-specific collection challenges reflect the diversity of bio-based materials. Drop-in bio-based plastics (bio-PE, bio-PP, bio-PET, bio-PBAT) enter conventional plastic collection streams and cannot be differentiated from fossil counterparts without sophisticated tracking systems. These materials benefit from established collection infrastructure achieving 65% recycling rates under separate collection schemes but only 5% under mixed collection. However, the renewable origin and climate benefits of bio-based content remain untracked and uncredited in conventional recycling statistics.

Novel bio-based polymers face greater collection obstacles. PLA and other biodegradable plastics appear

[1] https://ec.europa.eu/eurostat/databrowser/view/env_wasgen/default/table?lang=en

distributed across packaging waste, biowaste, and residual waste streams due to consumer confusion, preventing efficient collection for any single end-of-life pathway. Manual sorting analysis in Austria found biodegradable items scattered across all three bins, with sorting patterns varying by product type (carrier bags versus dustbin bags). This dispersion reduces effective collection rates for all intended pathways – mechanical recycling, industrial composting, and even energy recovery. Modern separation units are fully able to separate PLA out of mixed waste streams.

Comparison to conventional plastics reveals significant collection infrastructure advantages for fossil-based materials. Conventional plastics benefit from decades of system development, consumer education, and regulatory frameworks mandating collection targets. Separate collection systems for conventional plastic packaging achieve 13 times higher recycling rates compared to mixed waste collection, but are so far limited to PET. The EU Waste Framework Directive (Directive 2008/98/EC) imposes recycling targets creating regulatory pressure to improve collection (65% recycling of municipal waste by 2035) though these targets generally do not differentiate bio-based from fossil-based plastics.

Collection rates are not determined by feedstock and whether a plastic is bio-based or not , but rather by application and shape. Bio-based PE will have exactly the same collection rate as fossil-based PE. Collection rates are higher for applications in cars or building and construction and lower for applications like packaging. Comprehensive data can be found here, but are locked behind a paywall: https://plasteax.earth/#Explore-data

End-of-life fate of biobased plastics (e.g. recycled, composted, incinerated) (Annex 6, Environmental Performance, ID 9)

In general, European statistics indicate that significant shares of plastics wastes are landfilled or incinerated, with actual material recycling rates of plastics-to-plastics being around 10%. Hosseini et al. (2025) report a global recycling share of ~10% of primary production (~380 Mt plastics produced, 37.96 Mt recycled), and more specifically for Europe, that of the 30 Mt of plastics waste generated in the EU in 2022, 4.2 Mt are actually recycled (14%), 7.2 Mt are incinerated and 14 Mt are landfilled (see Figure 20). For end-of-life fate of bio-based polymers, it needs to be distinguished between drop-in chemicals and the dedicated polymers.

For drop-in polymers like bio-PE, bio-PP or bio-PET, the EoL fate is technically identical to their conventional counterparts. Therefore, their recycling, incineration, and landfill rates can be reasonably approximated by the average figures for all plastics. That said, it is worth to note that there are some drop-in polymers (in particular epoxies), which are barely recycled at all. Additional data is available for different markets in the EU, e.g. via official EU statistics, data by Conversio (Conversio, 2025), Plastics Europe (Plastics Europe, 2024) or online platforms like Plasteax.earth (Link).

For dedicated polymers, the picture is a bit more diverse. For most of the dedicated bio-based polymers, mechanical recycling would be possible, but infrastructure is still missing – the core challenge here is a "scale-infrastructure dilemma" because these polymers only constitute a very low share (~1%) of total plastic waste by weight (SYSTEMIQ, 2022). This is too small a volume to justify large-scale investments in dedicated sorting and recycling infrastructure. For now, that means that these materials are still incinerated of land-filled, depending on different countries. However, that is again not a technical limitation, but a commercial one and a known dilemma for new materials. As long as volumes are small, no investments into recycling capacities happen. And on the other side, small-volume polymers score worse because they are not recycled and thus cannot reach bigger quantities. As soon as the total volume increases to about 5%, collecting, separating and recycling will become a economic feasible option

PLA can be composted under industrial conditions as well as recycled. However, no exact market data exists.

PEF has the option to enter PET recycling streams (Avantium, 2025), providing a solid example where a new dedicated polymer can enter an existing, efficient and well developed recycling stream. That said, it is limited to an upper threshold (5-10%) because then PET qualities start to get impacted.

Potential alignment of BBP waste with respect to the waste hierarchy at the end of life (Annex 6, Environmental Performance, ID 10)

Principally, bio-based plastics waste demonstrates high, but variable alignment with the waste hierarchy, with room for improvement in preventing downcycling and maximising resource efficiency. The waste hierarchy framework – prioritising prevention, reuse, recycling, energy recovery, and disposal in descending order of environmental preference – provides a structured approach for evaluating bio-based plastic sustainability (EEA, 2020).

Current alignment status reveals that bio-based plastics occupy multiple hierarchy levels depending on polymer type, application, and available infrastructure. At the highest levels (prevention and reuse), bio-based plastics perform comparably to conventional plastics. Prevention opportunities include lightweighting enabled by high-performance formulations, reducing overall material consumption while maintaining functionality. Reuse scenarios exist for durable bio-based plastic products including food containers, reusable coffee cups, and carrier bags, though single-use applications dominate current market share at 45% in packaging (European Bioplastics, 2024).

At the recycling level, bio-based plastic alignment varies significantly, as already indicated. Drop-in materials (bio-PE, bio-PET, bio-PP) integrate seamlessly into mechanical recycling streams, achieving high hierarchy alignment equivalent to fossil counterparts while offering renewable feedstock benefits. These materials undergo multiple recycling loops before property degradation necessitates downcycling or disposal. Novel biopolymers (PLA, PHA, PBS) are from a technical point of view fully recyclable, but face challenges entering established recycling infrastructure, with post-consumer recycling awaiting sufficient volumes to justify dedicated processing facilities. Where recycling occurs, bio-based plastics provide environmental advantages through negative GWP values as recycled material offsets virgin fossil-based production.

Organic recycling (composting, anaerobic digestion) represents a unique waste hierarchy position for biodegradable bio-based plastics. While ranked below mechanical recycling in material value retention, organic recycling enables circular nutrient flows, circular carbon (and hydrogen/oxygen), and renewable energy generation unavailable to conventional plastics. Home composting is a valid component that is difficult to track and quantify. Industrial composting facilities process certified compostable plastics into soil amendments, closing biological carbon cycles. Anaerobic digestion captures biogas for energy while producing digestate fertiliser. However, debate continues regarding whether organic recycling constitutes true “recycling” under waste hierarchy definitions, as material structure is not preserved. But it is in line with the EU waste hierarchy, which defines recycling as “any recovery operation by which waste materials are reprocessed into products, materials or substances whether for the original or other purposes” (WFD 2008/98/EC, Article 3.17).

Energy recovery through incineration with energy capture ranks lower in the hierarchy but serves as a viable end-of-life option when higher-ranked alternatives are unavailable. Bio-based plastics generate renewable energy during incineration, releasing biogenic carbon originally sequestered from the atmosphere rather than fossil carbon, though material value is permanently lost. EUBP considers incineration with energy recovery a viable choice for bio-based plastics given renewable energy production advantages over fossil plastics.

In this context, CCU as a concept is an interesting case as it is not properly defined on the waste hierarchy. From our perspective should belong to the recycling category, as the carbon is actually kept in the technosphere, similar to other recycling technologies. If the captured CO_2 in biogenic, it could even be considered as carbon removal.

Landfilling represents the least desirable hierarchy level, creating environmental risks without resource recovery. Despite EU efforts to reduce landfilling through the Landfill Directive's 2030 ban on separately collected waste disposal, almost 25% of plastic waste was still landfilled in 2022, including 11% of separately collected material (Plastics Europe, 2024). Biodegradable bio-based plastics landfilled under anaerobic conditions generate methane emissions, which can drastically increase GWP if not properly captured and utilised, while non-biodegradable bio-based plastics persist indefinitely like conventional plastics.

Task 3: Desk research on sustainability requirements for biobased feedstock in plastic packaging

Existing JRC and EC work and academic and technical literature

The European Commission has developed several documents that directly address the assessment of bio-based raw materials.

Following an overall European Strategy for Plastics in a Circular Economy (European Commission, 2018) (COM/2018/28 final) – as a key part of the Circular Economy Action Plan – the Communication for an EU policy framework on biobased, biodegradable and compostable plastics (European Commission, 2022) (COM/2022/682 final), published in 2022, aims to a) improve the understanding around such plastics and clarify where they can bring genuine environmental benefits, b) guide citizens, public authorities and businesses, and c) prevent differentes at national level and fragmentation of the market.

In response to the above plastics strategy, the JRC was tasked with developing a harmonised, so-called **Plastics LCA method** (Nessi et al., 2021) to assess the environmental impact of plastic products made from various raw materials, including fossil resources, biomass and CO_2. This method is intended to enable reproducible and consistent studies at EU level and is an important reference for all work on setting requirements for bio-based raw materials.

In the method, for bio-based plastic products there are defined processes and activities that shall be included under the "Raw Material Acquisition and Pre-processing" stage, both for primary biomass sources and for bio-based waste and by-products. These provide a good overview of processes and activities of relevance when assessing the sustainability of feedstocks. Additionally, the method describes in detail relevant modelling requirements for conducting a life-cycle assessment, with e.g. a highly granular list of activities, input and emissions to be considered when modelling agricultural production. The method does not provide specific provisions on sustainability requirements or criteria.

A recent JRC study (Sinkko et al., 2025) examines the environmental impact of replacing conventional products with bioeconomic innovations. It provides evidence of how bio-based options can reduce the EU's environmental impacts highlighting both benefits (such as lower climate impact and reduced consumption of fossil resources) and trade-offs (such as potential increases in land use and eutrophication). This analysis is directly applicable to understanding the consequences of setting specific raw material requirements. It concludes with a general rule of thumb when it comes to bio-based vs fossil-based products: "*Bio-based plastics appear to have higher impacts on some impact categories such as land use and eutrophication[…]. **Carefully designed sustainability criteria for bio-based feedstocks** (e.g. using sustainable feedstocks such as lignocellulosic biomass, algae and waste materials) **are key***."

The study concluded with some indications on main criteria considered for the identification of relevant bioeconomy solutions:

Environmental criteria:

- *Contribution of bio-based innovations to **climate change mitigation** (greenhouses gases) and **adaptation**;*

- *Other environmental impacts of bio-based innovations within a life cycle approach, considering the **other impact categories beyond Climate Change**, as in the Environmental Footprint method, including effects on soil health, land use change and biodiversity;*
- ***Availability** and **sustainability of primary feedstock**;*
- ***Use of organic waste and by-products as feedstock**, to limit the use of primary biomass and competition with other uses of biomasses.*
- ***End of Life collection rate** and **End of Life management** options.*

Market related criteria:

- *Indications on bio-based value chains **with high potential in terms of market demand**;*
- ***Production costs of bio-based innovations**, as a key indicator for scalability and competitiveness of sustainable alternatives versus conventional ones;*
- ***State of technological maturity**, potential technological progress*

The above list of criteria is focused on identifying relevant bioeconomy solutions, and this report here intends to provide reliable input on each. The strategic documents of the Commission so far focused on the transition towards circularity & carbon-neutrality (Plastics strategy), reducing plastics litter (SUPD, Directive (EU) 2019/904) and prioritising organic waste & side-streams for bio-based plastics (European Commission, 2022) When it comes to sustainability requirements for bio-based feedstock on a larger scale, an additional key focus needs to be on the aspects of "**availability** and **sustainability of primary feedstock**" – which is the main aspect covered in the following in this chapter.

The establishment of robust sustainability criteria for biomass used in plastic packaging is essential to ensure a genuine positive environmental and social impact. Drawing from EU policy frameworks and academic literature (Mai-Moulin et al., 2020 and Blas Mola-Yudego et al., 2024), these criteria can be structured into three core pillars:

- **Environmental Criteria** focus on mitigating climate impact and preserving ecosystems. The paramount objective is the **reduction of greenhouse gas (GHG) emissions** across the entire lifecycle compared to fossil alternatives. This is complemented by the need to **protect air, soil, and water quality** from pollution, alongside the prudent management and **reduction of water usage**, especially in water-stressed regions.

- **Land & Biodiversity Criteria** address the direct impacts of biomass cultivation on terrestrial ecosystems. Central to this is safeguarding land with high carbon stocks, such as forests and peatlands, and implementing practices that **increase carbon stocks on land**. Furthermore, it is critical to **take measures to maintain and improve biodiversity**, which is operationalized through the creation and application of a **sustainable forest or land management plan**. A key lever to prevent the displacement of agricultural production is the **restriction of high Indirect Land-Use Change (iLUC)-risk feedstocks** and the promotion of those with **low iLUC-risk**, such as wastes, residues, and crops grown on degraded land.

- **Social Criteria** ensure that the sourcing of biomass is equitable and just. This requires full **compliance with human rights and labour rights**, guaranteeing safe working conditions and fair wages. It also entails the respect for **land and water rights**, particularly involving the recognition of customary rights of local communities and indigenous peoples, and ensuring that biomass production does not adversely affect their access to vital resources.

This holistic framework can help to ensure that the transition to bio-based feedstocks contributes meaningfully to the goals of a circular and carbon-neutral economy.

The Renewable Energy Directive (RED) is a key EU regulation that sets legally binding targets for the share of energy from renewable sources in the EU's energy mix. For the context of this chapter, the RED established a set of sustainability and greenhouse gas emissions saving criteria that serve as a benchmark for biomass used in energy applications, including biofuels and bioliquids.

Existing RED sustainability framework

The Renewable Energy Directive

- DIRECTIVE (EU) 2023/2413 on **the promotion of energy from renewable sources**
- Initial Directive from 2018 is continuously revised – latest revision in 2023
- **Sustainability criteria for biomass** first implemented in RED II(I)
- RED criteria for biomass are **point of reference** in current policy – but they only refer to energy uses
- Energy uses obligated to fulfil these criteria also have incentives in place for fulfilling the sustainability criteria.
- Sustainability criteria for the chemicals and materials sectors are non-existent, although the sustainbility criteria in RED II(I) are informally used as reference.
    - **no incentives** exist to fulfil these criteria.

RED II(I) Sustainability Criteria Requirements

- The biomass may not originate from an area with a **high biodiversity value** such as primary forest, protected nature areas and grasslands with high biodiversity.
- The biomass may not come from lands with **high carbon stock** such as wetlands and permanently forested areas. This also applies to peatlands unless demonstration shows that biomass production does not lead to the dewatering of soil that was not dewatered before. In this regard, the status of the ground in January 2008 is the baseline.
- Forest biomass may only stem from **areas that are harvested legally and sustainably**, and must meet certain **LULUCF criteria**
- **Greenhouse gas emission savings** compared to fossil benchmark

Table 9: Mapping of sustanability criteria covered by the Renewable Energy Directive

Environmental criteria		Land criteria	
Reduce GHG emissions	X	Increase carbon stock on land / Exclude land with high carbon stock	X
Protection of air soil and water	partly	Take measures to maintain and improve biodiversity	partly
Waste usage and reduction	–	Create and apply a sustainable forest management plan	X

		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	X
Social aspects		**Social aspects**	
Compliance with human rights	–	Compliance with land rights	–
Compliance with labour rights	–	Compliance with water rights	–

Existing certification schemes, greenhouse gas emission savings criteria and cascading principle

Today, a growing number of product and process attributes can be independently verified through certification, providing essential transparency for sustainability claims. Key certifiable aspects include:

- Bio-based & bio-based carbon share
- Bio-attributed shares
- Recycling shares
- Sustainability of biomass
- Carbon footprints, regenerative agriculture
- Biodegradability & compostability

Certification systems

- Focus on specific feedstocks, materials or similar – but can be applied through the value chain
- Can be multi- or single-issue
- Third-party verified
- Based on private standards, even if validated by a wide range of stakeholders

Life-cycle assessments

- Standardised by international standards (voluntary)
- Considers the whole life-cycle of a product (cradle-to-grave)
- Multiple impact factors
- Calculated by companies or by independent entities (review possible but not mandatory)
- No social aspects included (S-LCA is a separate method)

Legal requirements

- Only available for limited number of sectors/products, but number is growing
- Often related to market access
- Assessment must be comparable to allow political decisions

Risk assessment

- Not standardised
- High-level
- Needs to consider regional aspects

There is a vast number of sustainability certifications that are available today, for different aspects (e.g. vegan, organic, climate neutral, social like fairtrade, compostability, etc.) and different sectors (e.g. textiles, building, packaging, etc.). 7 major sustainability certificates have been assessed in further detail, largely based on their relevance and market shares – these 7 cover the vast majority of the sustainability certification market for bio-based feedstocks. The selected certification systems are: **ISCC Plus**, **RSB**, **RSPO**, **Better Biomass**, **FSC**, **Bonsucro** and **REDcert**. Table 10 below shows an overview of the key criteria addressed across these 7 certification systems, more details can be found in Annex III.

Table 10: Mapping of relevant sustainability criteria for biomass across 7 relevant certification systems.

Environmental criteria		Land-use criteria	
Reduce GHG emissions	x6	Increase carbon stock on land / Exclude land with high carbon stock	x7
Protection of air soil and water	x6	Take measures to maintain and improve biodiversity	x5
Waste usage and reduction	x5	Create and apply a sustainable forest management plan	x1 3 x n/a 2 x refer to other certificate
		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	x4 1 x n/a 1 x refer to other certificate
Social aspects		**Social aspects**	
Compliance with human rights	x7	Compliance with land rights	x6
Compliance with labour rights	x7	Compliance with water rights	x6

Further policy files of relevance to sustainability certification

Although the Renewable Energy Directive (RED) set out the initial sustainability criteria for biofuels and bioliquids, the EU's regulatory framework for sustainable biomass has grown considerably. Several key policy documents now complement and, in some cases, extend beyond the scope of the RED, creating a more complex and demanding environment for certification systems. Together, these regulations push certification towards greater comprehensiveness, covering not only greenhouse gas savings, but also broader environmental and social safeguards, supply chain integrity and circular economy principles.

The following table summarises the relevance of these policies to biomass sustainability certification:

Policy Instrument	Primary Focus & Relevance to Certification	Key Addition Beyond RED II Baseline
EU Taxonomy Regulation (2020/852)	Provides a **classification system** for "environmentally sustainable" economic activities. It sets detailed **Technical Screening Criteria (TSC)** for activities like bioenergy.	Defines **substantial contribution** to climate objectives and strict **Do No Significant Harm (DNSH)** criteria across other environmental goals (biodiversity, water, circular economy), often going beyond RED's GHG-focused approach.
Deforestation-Free Products Regulation (EUDR) (2023/1115)	Mandates **supply chain due diligence** to ensure key commodities (soy, palm oil, wood, cattle, rubber, coffee, cocoa) and derived products are **deforestation-free** (post-Dec 2020).	Explicitly targets **land-use change from deforestation and forest degradation**, requiring precise **geolocation data** of feedstock origin. It is the only major policy in this scope with explicit **social**

		sustainability (human rights) provisions linked to indigenous communities.
Ecodesign for Sustainable Products Regulation (ESPR) (2024/1781)	Establishes **horizontal rules** for product durability, repairability, and recyclability. It acknowledges the use of **renewable/ sustainable materials** as a positive parameter.	Shifts focus to the **final product's environmental performance**, potentially rewarding the use of certified sustainable biomass in sectors like textiles or plastics as part of a product's overall sustainability score.
Green Claims Directive (Proposal, effectively paused)	Lays down rules for **substantiating and communicating** voluntary environmental claims (e.g., "made from sustainable biomass").	Demands **robust, verified, and comparable evidence** for any sustainability claim. This will raise the bar for the credibility of certificates and require stricter oversight of certification claims made to consumers.

A comparison table of the here mentioned policy files and certification systems in context of biomass sustainability certification is provided in Figure 21.

Interplay and Direction for Certification Schemes

The combined force of these policies signals a clear trajectory for biomass certification. This evolving landscape develops sustainability certification from a singular focus on bioenergy toward a **cross-sectoral, supply-chain-wide requirement for biomass**. Future-proof schemes will need to integrate criteria from multiple regulations to serve the EU market effectively. For instance, a certificate proving compliance with RED II may not automatically satisfy the EUDR's deforestation due diligence requirements or the Taxonomy's DNSH criteria on biodiversity. Certification bodies are therefore under pressure to **expand their audits** to cover geolocation tracing, broader environmental impact assessments, and social governance, while companies are concerned about additional administrative burden to ensure all requirements can be met.

Principle	Criterion	Mapping of Criteria / Indicators / Requirements to types of sources											
		EU Taxonomy	ESPR	Green Claims Directive	Deforestation-free Products Regulation	REDIII	ISCC PLUS	RSB	Better Biomass	REDcert	FSC	RSPO	International standards
MITIGATE GLOBAL WARMING	Exclude land with high carbon stock	✓				✓	✓	✓	✓	✓		✓	✓
	Increase **carbon stock** on land					✓							
	Reduce **GHG emissions**	✓				✓	✓	✓	✓				✓
	Use **fertilisers** efficiently	✓											
	Create and apply a **forest management plan**	✓				✓					✓	✓	
	Restrict the use of high **iLUC-risk** feedstock	✓			✓	✓							
	Use only **low iLUC-risk** feedstock	✓			✓	✓	✓	✓	✓	✓			
PROTECT AND IMPROVE BIODIVERSITY	**Exclude land** with high biodiversity	✓			✓	✓	✓	✓	✓	✓		✓	✓
	Take **measures** to maintain and improve **biodiversity**	✓			✓		✓	✓	✓		✓		
	Minimize **harvesting** impacts on biodiversity				✓	✓	✓	✓	✓		✓	✓	
	Apply good practices for the use of **plant protection products** (PPPs) to protect biodiversity	✓					✓	✓	✓	✓	✓	✓	
	Apply good practices on **integrated pest management** to protect biodiversity	✓					✓	✓	✓	✓	✓	✓	
	Prohibition of highly **invasive species**	✓					✓	✓	✓				
PROTECT AND IMPROVE WATER RESOURCES	Avoid **depletion** of surface or groundwater resources beyond replenishment capacities						✓	✓	✓		✓	✓	✓
	Avoidance of **hazardous chemicals**	✓					✓	✓	✓	✓	✓	✓	
	Apply good practices for good use, storage, handling and disposal of **(agro)chemicals**	✓					✓	✓	✓	✓	✓	✓	
	Apply good practices for the use of plant protection products (PPPs) to protect biodiversity	✓					✓	✓	✓	✓	✓	✓	✓
	Take **cleaning up measures** in case of pollution	✓									✓		
PRO-TECT AND IMP-ROVE SOIL QUA-LITY AND PROD UCTI-VITY	Good agricultural practices to protect and improve **soil quaility and productivity** are taken	✓				✓	✓	✓	✓	✓	✓	✓	✓
PRO-TECT AND IMPRO VE AIR QUA-LITY	Avoid **open air burning**	✓					✓	✓	✓	✓		✓	
	Control or eliminate the use of dangerous chemicals and pesticides						✓	✓	✓	✓	✓	✓	
PRO MO-TE SOC IAL JUS TICE	Compliance with human, labour and land rights				✓		✓	✓	✓	✓	✓	✓	

Figure 21: Mapping matrix of criteria / indicators / requirements for biomass sustainability from different policy documents, certification systems, and international standards

Cascading Use

In addition to the established sustainability criteria for biomass, the principle of cascading use is a vital yet frequently overlooked means of maximising sustainable use of biomass. Although it is widely endorsed in policy rhetoric, its practical implementation remains limited, highlighting the need to recognise it as a distinct and vital area. Harnessing its potential fully requires moving from conceptual support to measurable application, for instance through clear indicators.

The core argument for cascading use is that it enhances resource efficiency, a cornerstone of sustainability. It is defined as a strategy "*to use biomass for materials for as long, as often and as efficiently as possible, and only recover energy from it at the end of the product life cycle*" (UBA, 2014). This sequential use – for example, transitioning from timber construction to particle board production and ultimately energy recovery – increases the productivity and value generated from each unit of biomass. Using the same biomass multiple times for material purposes reduces the pressure to extract virgin resources from forests and agricultural land. This directly contributes to more sustainable land management, helps to protect ecosystems and biodiversity, and mitigates conflicts over biomass allocation.

From a climate perspective, cascading use is superior to direct bioenergy generation. A life cycle assessment study on wood cascades shows that, in most cases, the environmental impact is lower for cascading than for energetic use (Höglmeier et al., 2015). This is because material use often enables a "double substitution": the bio-based product first replaces a fossil-based counterpart (e.g. plastic or concrete), and at the end of its life, when it is used for energy, it replaces a fossil fuel. As Carus et al. (2014) state, "*Through the double substitution achieved by material use, more CO_2 is reduced over the whole lifecycle than with direct energy use*". Furthermore, the use of materials provides temporary carbon storage, keeping biogenic carbon out of the atmosphere for the product's lifetime (Dammer et al., 2016).

However, the current political framework hinders this more sustainable pathway of biomass utilisation. Subsidies and incentives under schemes such as the RED create "strong market intervention" that favours the direct energetic use of biomass, rendering material uses "hardly competitive" (Carus et al., 2015). This not only distorts the market, but also locks biomass into a single, less resource-efficient use – the significant additional sustainability benefits of cascading are forfeited. To overcome these barriers and translate the principle into practice, robust quantification methods are essential.

In this context, we would highlight the Biomass Utilisation Factor (BUF), developed by nova-Institute, as a metric that combines 'cascading use' (how often biomass is used) and 'production efficiency' (how much of the biomass is utilised) into a single indicator (vom Berg et al., 2022). A BUF above 1.0 indicates that the biomass has been used more than once on average. For example, the BUF for the European wood sector was found to be 1.51, whereas a well-established cascade such as bio-PET in bottles can achieve a BUF of 4.97. This indicator enables policymakers and industries to measure performance, set targets and design support schemes that genuinely 'respect the cascading principle', as recently demanded by the European Commission. By adopting such clear metrics, we can move the concept of cascading use from a theoretical ideal to a measurable and implementable component of a sustainable bioeconomy.

Evaluation of recent position papers

The ongoing assessment for the EU Packaging and Packaging Waste Regulation (PPWR, Regulation (EU) 2025/40) has brought the issue of sustainable biomass for chemicals and plastics to the forefront. As the EU seeks to defossilise its economy, biomass is a critical renewable carbon source. However, its use raises complex questions about sustainability, sourcing, and fair competition with the bioenergy sector, which already operates under a well-defined incentive structure (the Renewable Energy Directive - RED).

his requires a clear, harmonised, and supportive EU policy framework. The central challenge is to ensure that sustainability criteria for biomass used in materials are robust enough to guarantee genuine environmental benefits, but not so restrictive or unbalanced that they stifle innovation and prevent the sector from scaling up to compete with both fossil-based and bioenergy uses of biomass. As a consequence, several actors in this field have published position papers. Highlighted below are the positions of Cefic (Cefic, 2025), European Bioplastics (EUBP, 2025) and the Renewable Carbon Initiative (RCI, 2025), which are summarised below:

a) Renewable Carbon Initiative (RCI)

RCI's position provides a detailed blueprint for “horizontal” sustainability criteria that apply across all biomass uses, arguing that criteria are only effective when linked to incentives.

RCI’s main recommendations:

- **Adopt and Adapt RED III:** Strongly supports using **Article 29 of RED III** as the foundation for sustainability criteria for biomass in chemicals and materials to ensure a level playing field. However, it calls for specific **adaptations**, particularly for forestry biomass (e.g., aligning cut-off dates with the EU Deforestation Regulation and focusing on current management practices rather than historical land use).
- **Link Criteria to Incentives:** Emphasises that sustainability criteria must be legally binding only when linked to market-pull **incentives and quotas**, mirroring the model used for biofuels.
- **No Caps on Feedstocks: Strongly opposes any cap** on the use of food and feed crops for material production, arguing there is no evidence it causes food insecurity and that these crops offer high land-use efficiency and valuable co-products.
- **Pragmatic GHG Accounting:** Acknowledges that GHG savings calculations are more complex for materials than for energy and supports a pragmatic approach, such as demonstrating a lower carbon footprint than a fossil counterpart using standard LCA methods (e.g., ISO 14067), rather than applying fixed percentage reduction targets.

b) Cefic

Cefic's position focuses on creating clear definitions and a level playing field to accelerate the use of biomass-derived plastics.

Cefic’s Main Recommendations:

- **Clarify Terminology:** Proposes a new, overarching term **"biomass-derived plastics"** to encompass both **"bio-based"** (measured via 14C) and **"bio-attributed"** (allocated via certified mass balance) plastics. This aims for technology neutrality.

- **Set Pragmatic Targets:** Supports the PPWR's review for potential targets but insists they must be realistic, based on a comprehensive impact assessment, and include both bio-based and bio-attributed plastics.
- **Harmonise Sustainability Criteria:** Supports using the sustainability criteria from **Article 29 (2-7) of RED III** as a basis for biomass sourcing, regardless of its final use, to ensure a level playing field between energy and material sectors.
- **Implement the Cascading Principle Pragmatically:** Calls for incentives (e.g., stimulating policies, support for integrated processing facilities) to make material use of biomass competitive, rather than prescriptive mandates.

c) European Bioplastics (EUBP)
EUBP's position strongly argues that sustainability criteria must be paired with strong market-pull incentives to ensure the industry's growth.

EUBP's Main Recommendations:

- **Incentives Before Hurdles:** Emphasises that the introduction of sustainability criteria must be **paired with market-pull measures** such as mandatory bio-based content targets, tax credits, and access to financing.
- **Adapt RED III Criteria:** Supports using **Article 29 of RED III** as a basis but calls for specific adaptations. It argues that bio-based plastics should only need to demonstrate **comparative GHG emission reduction** against their fossil counterparts, not meet the specific, high percentage reduction thresholds required for biofuels.
- **Create a Level Playing Field:** Highlights the significant distortion caused by strong incentives for biomass in the energy sector and the lack thereof for materials. Demands "equally strong incentives" for all biomass applications to enable the **cascading principle** (material use over energy recovery).
- **Involve the Value Chain:** Stresses that the perspective of farmers and the entire value chain must be considered in policy-making.

Key Alignments Between the Positions

The three organisations show significant common ground, presenting a largely unified industry front on several key issues:

- **Support for RED III as a Basis:** All three explicitly support using the **sustainability criteria from Article 29 of RED III** as the starting point for defining sustainable biomass for material uses. This is the most significant alignment.
- **Need for a Level Playing Field:** There is unanimous agreement that the current policy framework is unbalanced.
- **Need for Incentives:** All argue that **binding sustainability criteria must be coupled with economic incentives** (like mandatory content targets) to create demand and ensure fair competition with the supported bioenergy sector.
- **Endorsement of the Cascading Principle:** All positions reference and support the **cascading use of biomass**, which prioritises material use over energy recovery to maximise value and circularity.
- **Recognition of Adaptation Needs:** Both RCI and EUBP explicitly state that the RED III criteria cannot be copied wholesale and require adaptations for the materials sector, particularly concerning GHG accounting and forestry.

Key Differences Between the Positions

While aligned on the broader goals, the organizations have distinct nuances and areas of emphasis:

- **RCI** provides the most **technically detailed framework** for adapting RED III, with specific suggestions for forestry and a strong, evidence-based rejection of feedstock caps.
- **Cefic** focuses on **technological neutrality and precise definitions**, aiming to create a clear and pragmatic regulatory box ("biomass-derived plastics") for all relevant technologies.
- **EUBP's** primary focus is on **market-pull and growth** for the bioplastics industry, consistently framing the issue as "incentives before further hurdles."
- **Approach to Feedstocks:**
    - **RCI** is the most vocal and detailed in **defending the use of food and feed crops**, dedicating a significant portion of its paper to arguing against caps.
    - **EUBP** also mentions using agricultural feedstocks and denies competition with food, but its primary focus is on regulatory fairness rather than a detailed debate on caps.
    - **Cefic** does not explicitly address the food-crop cap debate in this paper, focusing instead on overarching criteria and definitions.
- **Specifics on Forestry:**
    - **RCI** offers the most **concrete adaptations** for forest biomass, suggesting changes to cut-off dates and a greater reliance on existing forest certification schemes.
    - **EUBP** and **Cefic** express support for the forestry criteria in RED III but do not delve into the same level of specific proposed modifications.

Short conclusion:

There is a perceived “confidence gap” in sustainability certification of biomass for mandating bio-based content targets. But this gap is less about the existence of certification systems or their technical rigor, and more about systemic governance and market readiness. Potential gaps include questions on harmonisation & recognition (can the major schemes be recognised equally?) as well as the scale and integrity of auditing (a mandate would massively increase the volume, but the overall process for certification of biomass would stay the same).

The extensive, decade-long experience of certifying biomass for biofuels (established by RED) provides a strong foundation for achieving mandated targets for bio-based plastics. The necessary systems, standards and audit protocols already exist. Rather than reinventing them, the policy task is to activate them for a new sector by:

- **Referencing existing standards**: Legislation can directly reference established, application-agnostic schemes (ISCC, RSB, etc.) as proof of sustainable sourcing.
- **Creating a clear compliance signal**: A mandate provides the missing link, creating a stable demand signal that justifies investment in certified supply chains for the chemical sector.
- **Leveraging lessons learned**: Policies can build on governance improvements and lessons learned from the biofuel era to ensure even greater integrity from the outset.

- **Fine-tune with adaptations**: to harmonise regulatory requirements between policy files and accommodate for changes that warrant specific considerations for the respective application field. Where feasible, the existing system for biofuels should be transferred over and applied for biomass into bio-based polymers as well. Based on the different nature of energetic and material use – bio-based plastics involve longer and more complex use phases, diverse material properties, and different end-of-life pathways – some technical adaptations are therefore required. Many of these aspects are already being addressed by ongoing initiatives (e.g., the Product Environmental Footprint Technical Advisory Board, PEF TAB), and include for example methodological challenges such as accounting for biogenic carbon uptake in Life Cycle Assessments and higher complexity of applicable "counterparts" to compare to and benchmark with.

In short, the thriving certification landscape is a strength, not a weakness. Policymakers can have confidence in the fact that a proven tool already exists; the task is rather to apply it to a new strategic objective.

Task 4: Desk Research to Support the Feasibility Assessment for Setting Targets to Increase the Use of Biobased Feedstock in Plastic Packaging

The contractor will collect **available evidence** (such as academic and technical literature on the topic), **quantitative data and analyse available data for setting targets to increase the use of biobased feedstock in plastic packaging**, complemented with analysis of environmental and technical characteristics of recycling and recovery options (see Task 2), as well as drivers and barriers to the use of biobased feedstock in plastic packaging. It will address the possibility to have **biobased feedstock targets in plastic packaging. It will cover both global and EU dimension.**

Defossilisation Requires Biobased Plastics

The report, 'Evaluation of Recent Reports on the Future of a Net-Zero Chemical Industry in 2050', assesses 24 scenarios from 15 studies envisaging a net-zero chemical and plastic industry by 2050 (Harrandt et al., 2024). The analysis anticipates continued growth in global chemical production, projecting a 2.4-fold increase in global feedstock demand by 2050 compared to 2020 levels. Most of this expansion is projected to occur outside Europe, where feedstock volumes are expected to remain stable. To achieve net-zero emissions in plastic production, the industry is projected to undergo a significant shift in feedstocks, also called defossilisation. In average across all scenarios, the key renewable carbon sources are biomass (21%), carbon capture and utilisation (17%), and recycling (42%), while the remaining 19% comes from fossil sources with carbon capture and storage (Figure 22).

In all scenarios, feedstock supply relies on increasing demand for biobased chemicals and plastics. The biobased share across ten scenarios from seven reports is between 10% and 30% for plastics in 2050 (Figure 23, the middle 50% of the data).

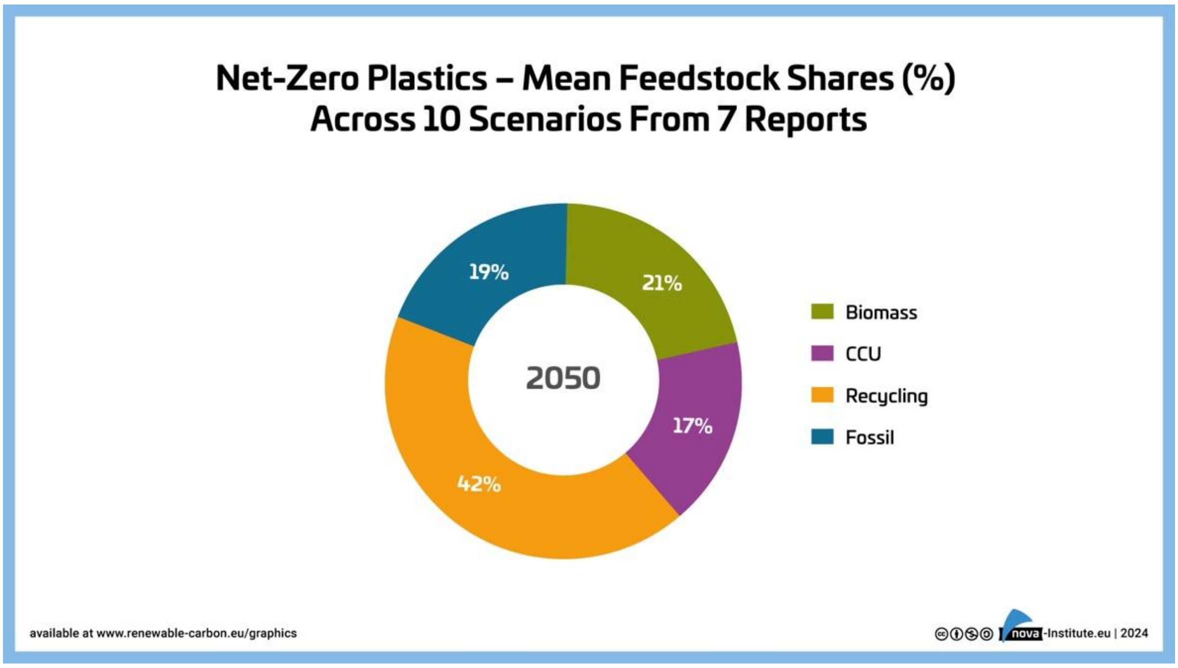

Figure 22: Mean feedstock shares for the 2050 net-zero plastics sector, derived from 10 scenarios across 7 reports (Harrandt et al., 2024)

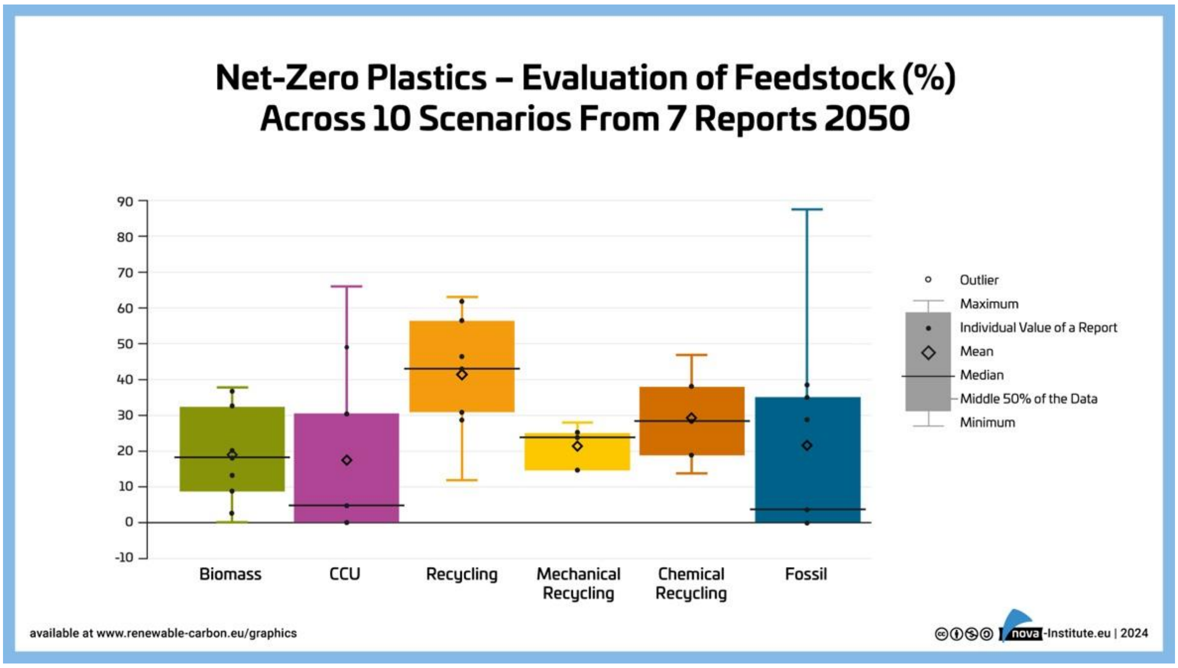

Figure 23: Mean feedstock shares projected for the 2050 net-zero chemical industry, based on 16 scenarios across 9 reports. (Harrandt et al., 2024)

Targets for Biobased Plastic Packaging and Other Sectors

Many national and regional bioeconomy strategies include high-level, ambitious goals. However, only a very few including concrete, quantitative quotas and targets to drive bio-based industries. Below are a few examples that we found within the framework of the project.

- **Malaysia:** The National Biotechnology Policy 2.0 set a target to contribute 5% to GDP by 2030: "Contribution of 5% of Gross Domestic Product (GDP) by biotechnology companies." (Malaysia Bioeconomy Development Corporation, 2022).
- **The Netherlands:** The Dutch Transition Agenda for Plastics plans to increase the percentage of recyclate and bio-based plastics to 41% recyclate and 15% bio-based plastics by 2030. This is a considerable increase compared to the current shares of approximately 9% recyclate and 1% bio-based. The Ministry of Infrastructure and Water Management has asked CE Delft to study the extent to which a mandatory percentage of recycled and/or bio-based plastics could help achieve this target and to assess the environmental and economic effects. (CE Delft, 2022).
- **European Commission**, December 2021: "At least 20% of the carbon used in the chemical and plastic products should be from sustainable non-fossil sources by 2030, in full consideration of the EU's biodiversity and circular economy objectives and of the upcoming policy framework for bio-based, biodegradable and compostable plastics." (European Commission, 2021).
- **Renewable Carbon Initiative (RCI)**: Discussed different issues in the context of targets for renewable carbon and defossilisation (vom Berg et al., 2025a):
    - "**Establish a Realistic Initial Target**: To allow industry to transition to renewable targets, the quotas should start at a level that is close to the current status quo (e.g. for the entire EU chemicals sector, it is 5.5%).
    - **Gradually Increase the Targets**: following examples from the energy & fuels sectors and CCS, the EU should consider a more granular increase of targets than usual, with many (e.g. yearly) milestones towards a 2050 vision. While targets provide a clear direction, 5-yearly intervals create difficulties for companies in matching production with significant upward jumps from one year to the next, leading both to over- and undersupply.
    - **Strong Targets are a Possibility**: The aviation industry, which competes for renewable carbon feedstocks, has already implemented ambitious targets for sustainable aviation fuels (SAF). These targets start at 6% in 2030 and progressively increase to 70% by 2050, demonstrating the feasibility of setting substantial goals for renewable carbon utilisation. However, learnings from the SAF targets should be applied, for example enabling flexibility mechanisms to counter short-term overproduction."

Methodology for the Development of Quotas for Biobased Plastics Packaging

For the first time ever, the PPWR and End-of-Life Vehicles Regulation (ELV) (European Commission, 2023) are discussing future quotas for bio-based plastics. These quotas could serve as a blueprint for other sectors in the future. This chapter is intended to support this development by providing input on how to derive feasible quotas in the context of existing recycled content targets and as a template for setting renewable carbon targets in other sectors too. The following segment presents a plausible scenario developed to illustrate a methodological approach how bio-based content targets might be determined and developed; it is not based on a fully applied, quantitative methodology.

Procedure for identifying suitable quotas in the PPWR

Step 1: Existing Regulation with a Target / Quota for Recycling 2040
Example: PPWR, Quotas for minimum recycled content in packaging from 2040

In case of the PPWR, existing minimum recycled content shares for plastics packaging have already been determined, with specific targets for the years 2030 and 2040, and for different types of plastic packaging.

Table 11: Recycled content targets envisioned by the PPWR for 2040

Packaging Type	Minimum Recycled Content, 2040	Remaining non-recycled content (Fossil, Bio, CO_2), 2040
PET packaging (food contact)	50%	50%
Other plastics (food contact)	25%	75%
Single-use plastics drink bottles	65%	35%
Other plastic packaging	65%	35%

Step 2: Reasonable bio- and CO_2-based targets from 2040
If the target is full defossilisation by 2050, there will still be some fossil plastics in packaging in 2040. For applications with a high recycling share, a remaining virgin fossil share of 10% in 2040 can be considered achievable for a 2050 net-zero trajectory; for applications with a lower recycling share, we consider a remaining fossil share at 20% realistic. The remaining share is divided into 80% bio-based (including bio-CO_2 and DAC) and 20% CO_2-based (fossil point sources), which seems realistic based on the projected upscaling timeline of CCU. A high bio-based share for food contact is sensible because this can easily be achieved with bio-based materials compared to mechanical recycling.

Table 12: Suggested, as reasonable considered targets for bio-based and CO_2-based packaging, complementing the recycled content targets of PPWR in 2040

Packaging Type	Remaining non-recycled content	Bio-based	CO_2-based	Virgin fossil
PET packaging (food contact)	50%	24%	6%	20%
Other plastics (food contact)	75%	44%	11%	20%
Single-use plastics drink bottles	35%	20%	5%	10%
Other plastic packaging	35%	20%	5%	10%

Step 3: Bio-based Content Targets – Starting Point 2024 and Linear Growth of Quotas Between 2024 -> 2040, Resulting Quota for 2030 and 2035

Current estimates indicate that the share of bio-based plastics in the market is approximately 1%, which serves as a realistic starting point also for bio-based packaging. The assumption is made that the 2040 targets can be achieved by using linear scaling from the existing 2024 data. This represents one of the options available (see Table 13). Another option is an exponential growth trajectory that starts slowly but rapidly accelerates to a significant rate. There are advantages and disadvantages to both options. The exponential growth of quotas could be in line with new investments for capacity building in new markets. Linear growth of quotas would first be met by imports (due to sufficient global capacities), followed by an increase in the share of domestic production after capacity building. This approach aligns more closely with net-zero targets.

As a learning from the SAF quotas under ReFuelEU Aviation, where 5-year interval increases create supply-demand mismatches, overcapacities, and early over-production due to abrupt demand jumps, more granular milestones – such as yearly targets –should be considered to smooth fluctuations, enhance investment certainty, and better align supply with evolving market needs (vom Berg et al., 2025a).

Table 13: Conceivable bio-based plastics packaging targets

Packaging Type	2024	2030	2035	2040
PET packaging (food contact)	1%	8%	15%	24%
Other plastics (food contact)	1%	10%	25%	44%
Single-use plastics drink bottles	1%	5%	12%	20%
Other plastic packaging	1%	5%	12%	20%

Step 4: Which Bio-based / Bio-attributed Plastics Will Count for the Quota? And how?

Open for discussion are several aspects of how to count bio-based content:

- Bio-based plastics with a minimum bio-based content of 20% are fully counted or only counted for their bio-based content? Both can be based on a solid certification systems.
- Next to bio-based plastics, bio-attributed plastics (via mass balancing) could also count, again based on a solid certification system (ISCC, RedCert, RSB).
- For biocomposites, not only the bio-based share in the plastic part but also the bio-based share of natural / cellulose fibres should count, because they can also substitute fossil plastics (high relevance for automotives, but also in packaging)

Step 5: Sustainability Criteria

- Only bio-based, bio-attributed or natural fibres that can demonstrate sustainable feedstock certification should count towards the content targets, in accordance with how it is handled for biofuels in the RED. These criteria should be developed based on the existing RED III criteria, but be further adapted based on relevant requirements, as e.g. detailed in the RCI position paper on such criteria (RCI, 2025) (for details, please also refer to Task 3).

Step 6: Production in the EU?

With an increased focus on strategic autonomy in Europe, one questions is whether parts of the overall bio-based content share fulfilment should be covered by bio-based, bio-attributed or natural fibres produced in the EU?

Realistically, the quotas determined in step 3 for earlier targets like 2030 and 2035 will be, most likely, mainly fulfilled by bio-based/bio-attributed plastics produced in Asia because it will take about 10 years to implement production plants in the EU and make import substitution realistic. This means that:

Either imports should be permitted to fulfil the quotas, or, if the quotas are only for EU production, they must be set much lower than those calculated in Step 3. Otherwise, the growth cannot be linear, but must start slowly and ramp up later. In practical application, a phased system allowing for initial import reliance with clear EU build-up requirements might be considered.

Drivers and barriers to the use of biobased feedstock in plastic packaging

The transition from fossil-based to biobased feedstocks for plastic packaging is complex, shaped by a compelling mix of sustainability drivers and significant economic and policy barriers. Understanding this interplay is essential for the future of green packaging.

Key drivers: The 'push' factors
The momentum behind biobased packaging is driven by a combination of environmental imperatives, market appeal and strategic circular economy goals.

- **Sustainability and climate action**: The urgent need to reduce the carbon footprint of materials is a primary driver. Biobased plastics substitute fossil carbon with renewable carbon, which directly addresses climate change and help to defossilise our economic system. A reduced dependency on fossil feedstocks also increases autonomy and strategic resilience. This is complemented by the development of new, environmentally friendly and less toxic chemical processes and biotechnology, which are often more sustainable than traditional petrochemical methods.
- **Positive consumer perception**: Biobased products have a demonstrably positive image among end consumers. This market demand encourages brands to adopt bioplastics as part of their corporate sustainability strategy, giving them a competitive advantage (Partanen et al., 2020).
- **Circular Economy Enabler**: Biobased feedstocks are essential for establishing and strengthening a true organic cycle within the circular economy. They can be designed to be compostable, enabling nutrients to be returned to the soil in packaging that is inevitably contaminated with food waste, thus complementing mechanical recycling streams.
- **Feedstock availability and diversity**: There is a wide range of potential feedstocks, including land-efficient first generation crops. Additionally, utilising non-food crops, lignocellulosic side streams (such as wood chips) and biogenic waste mitigates food versus fuel concerns and leverages underutilised resources. This is supported by systems for sustainable certification.

Key barriers: The 'hold-back' factors
Despite the strong drivers, widespread adoption is hindered by significant challenges, particularly in terms of policy and economics.

- **Policy and regulatory deficits**: A major barrier is the lack of a supportive policy framework. Compared to biofuels, which benefit from mandates and subsidies, there is no level playing field. Furthermore, the absence of policy support for demand creation (e.g. recycled content-style quotas for biobased content) and the failure to legally enforce the cascading principle mean that biomass is often used for single-use energy applications, which disadvantages higher-value material applications (vom Berg et al., 2025a).
- **Socio-environmental concerns**: NGOs and policymakers are right to raise concerns about potential competition with food crops and the pressure on land and biodiversity. In terms of food security, the cultivation of crops for industry is not as much of a risk as one might expect, and in fact can be beneficial in this regard, serving as an emergency

reserve (vom Berg et al., 2025b). While non-food feedstocks offer a solution, the risks and perception associated with large-scale biomass cultivation remain a significant barrier to public and political acceptance, particularly in Europe.

- **Economic competitiveness**: Biobased feedstocks are usually more expensive than well-established fossil alternatives. Producers also cannot compete with the economies of scale enjoyed by the century-old petrochemical industry. High upfront investment costs require a safe and predictable policy environment, which is currently lacking.
- **Integration into circular systems**: Due to the small market share of biobased packaging, infrastructures for collection, sorting and recycling are not yet in place on a large scale. This creates a chicken-and-egg problem: the lack of end-of-life solutions inhibits growth, and slow growth doesn't justify investment in new recycling streams.

Task 5: Desk research to support the feasibility assessment for possible equivalence between biobased content target and recycling content target

The contractor will collect available evidence to **evaluate the possibility to have an equivalence between biobased content targets and recycled content target**s and **how it could be operationalised**, including the role of biowaste. It will **address the sorting and recycling challenges** together with fossil-based plastics.

Evaluating Equivalence between Biobased and Recycled Content Targets for Plastic Packaging

The transition towards a net-zero and circular economy for plastics necessitates a fundamental defossilisation of the carbon used in packaging. While increasing recycled content is a primary and crucial strategy, achieving the required scale of fossil carbon substitution demands a complementary and multifaceted approach. Evidence suggests that establishing an equivalence between bio-based content and recycled content targets is not only possible but necessary, as both pathways contribute to the overarching goal of sustainable carbon cycles.

Guiding Principle: Carbon Circularity and the Necessity of Complementary Feedstocks

The core objective of policies like the EU's Sustainable Carbon Cycles Communication and industrial net-zero roadmaps is to replace fossil carbon with sustainable and circular carbon sources. A singular focus on mechanical recycling, while vital, faces systemic limitations:

- **Technical and Quality Limits:** Mechanical recycling has inherent constraints due to polymer degradation, contamination, and the complexity of multi-layer packaging, leading to downcycling.
- **Limited Availability:** The supply of high-quality recycled plastic is and will remain insufficient to meet total demand for virgin-grade applications, creating a ”recycling gap”, as visualised in Figure 24.

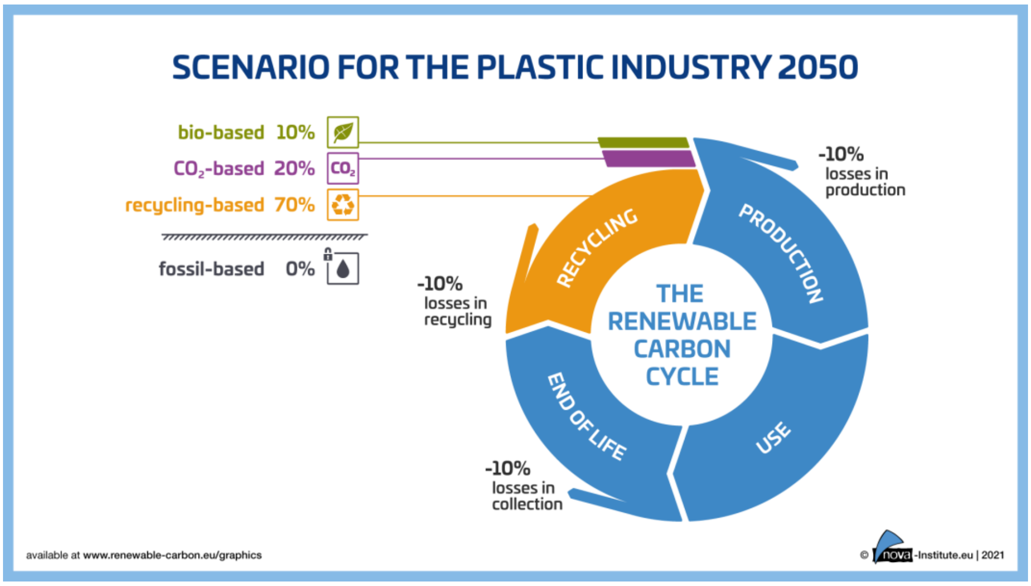

Figure 24: Scenario for the plastics industry 2050

Therefore, a strategy reliant solely on recycling is insufficient for complete defossilisation. A portfolio approach – integrating recycled content, bio-based feedstocks, and carbon capture and utilisation – is essential to ensure security of supply and achieve climate targets. Bio-based plastics, derived from sustainably managed biomass, provide a direct and scalable substitute for fossil carbon, effectively closing and enabling a sustainable carbon cycle. All these options directly substitute virgin fossil feedstock, and enable the defossilisation of our carbon-dependent industries.

Arguments for Equivalence: A Multi-Criteria Perspective

Equivalence between bio-based and recycled content is not about being identical, but about delivering comparable and complementary benefits towards common policy goals. The following table outlines key criteria for this evaluation:

Table 14: Multi-criteria assessment of arguments for equivalence between recycled and bio-based content

Argument	Recycling-based	Bio-based	Comments
Recyclability	Yes (Limited by quality of mechanical recyclates, accumulation of toxics)	Yes (90% are thermoplastics, can be mec. / chem. Rec.)	Both material streams are fundamentally recyclable. The challenges (quality loss for recycling, sorting for bio-based) are technical and can be addressed with improved infrastructure and design, not inherent disqualifiers.
Role in a complete circular economy	Essential for the technical cycle.	Essential, in particular if organic cycle is included	Depends on the definition of a Circular Economy. If the organic cycle is included in the definition, bio-based is needed.

Role in sustainable carbon cycles	Yes, keeps existing carbon in circulation.	Yes, introduces renewable carbon into the system.	Both are indispensable – recycling can not fully close the carbon cycle, Bio-based (and CCU) provide the necessary “fresh/virgin” renewable carbon to fully defossilise and close the carbon cycles, as outlined in the SCC Communication.
Reduces reliance on virgin fossil / necessary for defossilisation	Yes, directly substitutes virgin fossil feedstock	Yes, directly substitutes virgin fossil feedstock	Both are required. In order to avoid filling the carbon and plastic packaging recycling gap with fossil carbon, bio-based carbon is essential
GHG emission reduction vs virgin fossil?	Yes, significant (approx. 30-70%)	Yes, significant (approx. 30-40 %)	Both pathways offer substantial and comparable GHG reduction benefits compared to the fossil benchmark. Exact values are technology-dependent, but direction and magnitude are positive for both.
Critical environmental aspects?	Mec. Rec: Accumulation of toxics, quality degradation	Biodiversity and Land-Use issues	Both have distinct environmental trade-offs. A smart policy values the avoided fossil emissions and encourages best practices to mitigate specific risks of each pathway.
Applicable in sensitive food packaging	Mech. Rec: No Chem. Rec: Yes	Yes	Bio-based plastics currently hold a key advantage here, as they can provide virgin-quality material for direct food contact where safety regulations limit the use of mechanical recyclates. This makes them equivalent to chemical recycling for this critical application.
Cumulation of toxic ingredients (plasticiser, additives)	Mech. Rec: Yes, a key challenge Chem. Rec: Can break down toxins	No, provides a “clean slate”, free from legacy substances	Bio-based materials offer a systemic solution to the growing concern of cumulative toxicity in the mechanical recycling stream. They can help "clean" the material cycle over the long term. Whether Chem. Rec. can destroy all toxics is dependent on technology
Additional options to overcome limits of mechanical recycling	Chem. Rec: Yes, can handle complex waste streams	- Yes, by adding the organic cycle - Chem. Rec of bio-based: Yes	Both bio-based feedstocks and chemical recycling provide parallel and complementary solutions to limitations of mechanical recycling,

			enhancing overall system resilience.
Ability to deliver virgin quality	Only with Chem. Rec.	Yes	For applications requiring virgin-quality material (e.g., high-performance, food-grade), both certified bio-based plastics and output from chemical recycling are functionally equivalent (and in these instances superior to limited mechanical recyclates).
Policy / Industry acceptance	Mec. Rec.: High Chem. Rec.: Growing, but mixed	Mixed, concerns often focused on feedstock issues	Acceptance is a dynamic aspect. A policy framework establishing equivalence would itself be a powerful tool to drive acceptance for all non-fossil solutions.
Consumer acceptance	Mixed, concerns about quality, “waste”	Generally more favoured, “natural”, “renewable”	Consumer perception currently favours bio-based, providing a market-driven driver that can be used to accelerate defossilisation, complementing the regulatory push for recycling.

Renewable Carbon as a Synergistic Framework

To operationalise sustainable carbon cycles, policymakers should think beyond siloed targets and consider both a high-level commitment to defossilisation (to ensure reduction of fossil feedstocks) and a flexible compliance system. For example, a broader “renewable carbon content” target could be achieved through a combination of certified recycled and bio-based (and CCU-based) content. This would unlock synergies and address system-wide challenges, and could be combined with an overall target and specific sub-targets that ensure ambitious recycling targets and at the same time create lead markets for bio-based (and CCU-based) options. The established SAF targets provide a recent regulatory example.

Complementary Functional Roles: While the pathways are not identical, they are functionally equivalent for specific needs. Bio-based plastics offer a key advantage in sensitive applications such as food-contact packaging, providing virgin-quality material that meets stringent safety regulations — an area in which mechanical recyclates are often restricted. Furthermore, bio-based materials offer a “clean slate”, helping to prevent the long-term accumulation of legacy toxins in the recycling stream.

The critical role of biowaste: Biowaste is essential in achieving this equivalence. It serves as a vital raw material for advanced bio-based plastics, avoiding competition with the food chain and ensuring that circularity of feedstocks is maximised. At the same time, certified compostable bio-based packaging can be integrated into the organic recycling stream alongside biowaste, creating an additional, functional circular pathway that complements the technical recycling stream for durable plastics.

The critical role of food crops in scaling up: Although non-food and waste feedstocks are important in the long term and have a positive public image, it is crucial to recognise that first-generation food crops such as sugar and starch are currently essential for expanding the bio-based plastics industry. Most leading bio-based polymers suitable for packaging, such as polylactic acid (PLA) and bio-PET, are derived from these crops. Their use is foundational because:

- Established scale and efficiency: Food crops benefit from highly efficient, well-established agricultural systems with high yields and robust logistics, providing the large, consistent volumes of feedstock required by the chemical industry.
- Technology platform: They are the primary and most economically viable feedstock for pioneering bio-refineries, enabling the initial market development and technological progress that will pave the way for more advanced, non-food feedstocks.

Responsible policy must not exclude these feedstocks outright, but rather ensure stringent sustainability certification to ensure they are sourced without causing deforestation, biodiversity loss or direct competition with food supplies in regulated markets.

Managing system integration: Integrating bio-based plastics into the recycling process is a manageable challenge (please also refer to the relevant segments in Task 2). “Drop-in” bio-based polymers (e.g. bio-PE and bio-PET) are fully compatible with existing mechanical recycling processes. Other bioplastics can be effectively separated using the same advanced sorting techniques (e.g. NIR spectroscopy) required for a high-quality multi-polymer recycling stream. This demonstrates that infrastructure investments in advanced recycling systems benefit both recycled and bio-based content.

Establishing policy equivalence between bio-based and recycled content is a pragmatic, evidence-based strategy to accelerate the defossilisation of plastic packaging. Bio-based and recycled content are two sides of the same coin: one optimises the technical cycle of carbon, and the other sustains the biological cycle. By recognising their combined value, the EU can harness their synergistic potential, enhance resource security and establish a more resilient, truly circular plastics packaging sector.

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Annex II – Further details on processing routes, feedstock needs, land and water use

Column R in the Excel document (Annex I) shows the tonnes of the respective feedstock that are needed to produce one tonne of polymer. The process pathways, feedstock needs from crop to feedstock (e.g. starch, sugar) and related land and water requirements are described in and taken from a detailed study by the German Institute for Bioplastics and Biocomposites, at Hochschule Hannover (IfBB, 2025). An example of the level of detail in the study is shown in Figure 25.

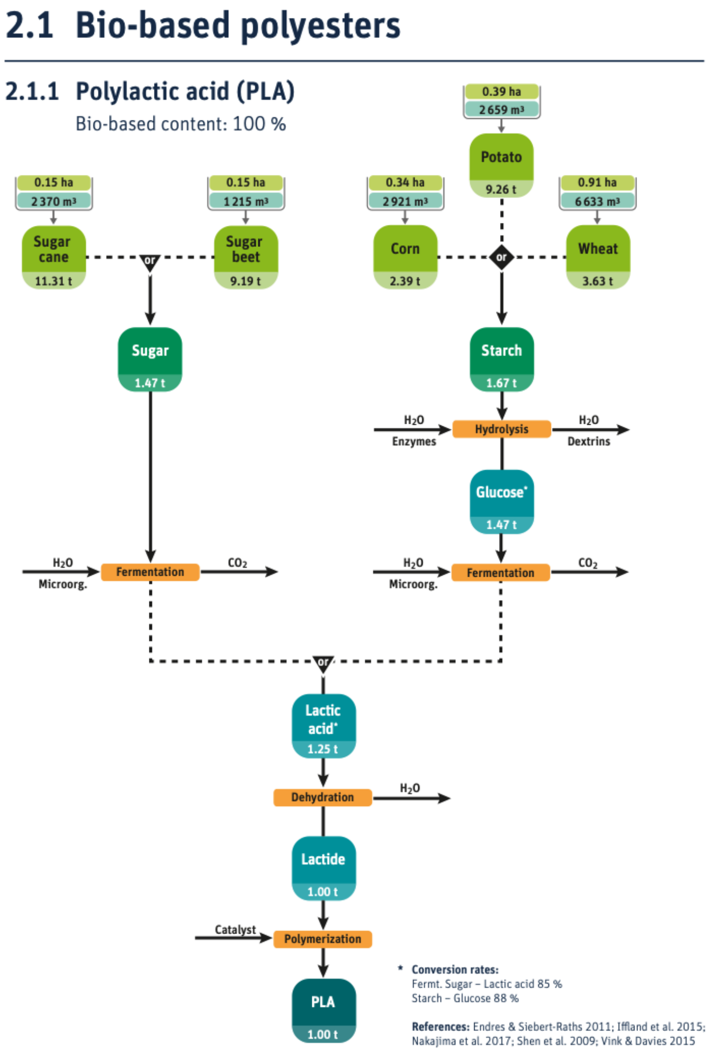

Figure 25: Pathways for bio-based PLA from different biomass feedstocks, with details on processing routes, feedstock needs, land and water use (IfBB 2025)

The strength of the study are the processing routes and the related land and water use. It shows that land demand for 1 kg bio-based polymer can be very different for different polymers. Please note that the report also contains information on production capacities, which we consider less reliable as those in our report (Skoczinski et al., 2025). Main reason ist hat IfBB mainly works with students and analysing press releases; nova, on the other hand, has a global network of experts in direct contact with a wide range of production companies. European Bioplastics has consequentially switched from the IfBB database to our data in the past.

Annex III – Details on 7 selected sustainability certification schemes for biomass

Bonsucro

Certification of sugar cane

Type of Framework: Certification System / Standard / Policy

Operating/ in force since: 2008

Legally Binding

Raw materials covered

Bonsucro is the leading global sustainability platform and standard for sugarcane, including production, processing and trade. The 'Bonsucro EU-RED Standard for Compliance with the EU Renewable Energy Directive Requirements' (also referred to as Bonsucro EU-RED Standard) has been designed as a voluntary add-on to the Bonsucro standards. The Bonsucro EU-RED Standard defines how, under certain conditions, sugar cane millers and their supplying area as well as supply chain operators are able to comply with the requirements in the EU Directive 2018/2001/EC on the promotion of the use of energy from renewable sources (recast). This Directive specifies sustainability requirements for biofuels, bioliquids and biomass fuels in the European Union.

Products covered

The Bonsucro Production Standard applies worldwide to any sugarcane mill and their supplying area wishing to sell sugarcane derived products as Bonsucro certified and make related claims. The Chain of Custody (ChoC) Standard relates to the supply of a product, including all stages from feedstock production up to consumption. It's proof that sourcing and trading responsibly, allowing you to make sustainability claims about sugarcane sourcing.

Table 15: Mapping of relevant sustainability criteria for biomass covered by Bonsucro

Environmental criteria		Land criteria	
Reduce GHG emissions	X	Increase carbon stock on land / Exclude land with high carbon stock	X
Protection of air soil and water	X	Take measures to maintain and improve biodiversity	X
Waste usage and reduction	X	Create and apply a sustainable forest management plan	Not Applicable
		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	Not Applicable
Social aspects		**Social aspects**	
Compliance with human rights	X	Compliance with land rights	X
Compliance with labour rights	X	Compliance with water rights	X

Additional Criteria – Bonsucro

Land criterion: The operator shall conduct a land-use change analysis of the unit of certification, to determine if land classified as a legally protected natural ecosystem (nationally or internationally), or classified as High Conservation Values (HCV), has not been converted to sugarcane on or after 1 January 2008.

Land criterion: The operator shall conduct a land-use change analysis of the unit of certification, to determine if land classified as natural ecosystem (either legally protected or not), or classified as HCV, has not been converted to agriculture on or after 1 January 2021.

Better Biomass

Dutch certification system for all kinds of biomass

Type of Framework: Certification System | Policy | Standard

Operating/ in force since: 2018

Legally Binding: ✗ | ✓

Raw Material Covered

Better Biomass is a certification scheme for sustainable bio energy and bio-based materials developed by the Netherlands Standardization Institute (NEN). Better Biomass is an international certification system for solid, liquid and gaseous biomass. The Better Biomass certificate is used to demonstrate the sustainability of the biomass used for energy, fuels or bio-based products.

https://betterbiomass.nl/app/uploads/2018/08/NCS-8080_2018-08-en-Better-Biomass-certification-scheme.pdf

Products Covered

Energy, fuels or bio-based products. Most of the certificates are for energy. Most used insolid residues and biogas sector. EU Red compliant.

BETTER BIOMASS
NTA 8080 CERTIFIED
WWW.BETTERBIOMASS.COM

Table 16: Mapping of relevant sustainability criteria for biomass covered by Better Biomass

Environmental criteria		Land criteria	
Reduce GHG emissions	X	Increase carbon stock on land / Exclude land with high carbon stock	X
Protection of air soil and water	X	Take measures to maintain and improve biodiversity	X
Waste usage and reduction	X	Create and apply a sustainable forest management plan	–
		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	X
Social aspects		**Social aspects**	
Compliance with human rights	X	Compliance with land rights	X
Compliance with labour rights	X	Compliance with water rights	X

Additional Criteria – Better Biomass

Land criterion: Exclude land with high biodiversity

Land criterion: Minimize harvesting impacts on biodiversity

Land criterion: Apply good practices for the use of plant protection products to protect biodiversity

Social aspects: The production of biomass for energy must not endanger the food supply and local biomass applications (energy supply, medicines, building materials)

Forest Stewardship Council (FSC)

Forest biomass certification

Type of Framework: **Certification System** | Policy | Standard

Operating/ in force since: 1995

Legally Binding

Raw Material Covered

Wood, Pulp, Non-timber Forest raw materials such as Bark, Bamboo and, Rattan, Natural Gums and Resins as well.

Products Covered

Wood Products (such as Engineered wood products and Furniture) , Pulp and paper products, and Non-timber forest products (NTFPs). Pulp products include also Viscose and Other Wood-based fibres and Textiles.

FSC www.fsc.org RECYCLED Made from recycled material FSC® C000000

Table 17: Mapping of relevant sustainability criteria for biomass covered by FSC

Environmental criteria		Land criteria	
Reduce GHG emissions	X	Increase carbon stock on land / Exclude land with high carbon stock	X
Protection of air soil and water	X	Take measures to maintain and improve biodiversity	X
Waste usage and reduction	–	Create and apply a sustainable forest management plan	X
		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	X
Social aspects		**Social aspects**	
Compliance with human rights	X	Compliance with land rights	X
Compliance with labour rights	X	Compliance with water rights	X

Additional Criteria – FSC

Environmental criterion: Keep harvesting below regeneration

Land criterion: Sample areas with more natural conditions identified (y/n)

Land criterion: Sample areas protected / restored to more natural conditions (y/n)

Land criterion: Protection of rare species and of native species

Land criterion: Measures to protect water bodies

ISCC PLUS – International Sustainability & Carbon Certification

A Germany-based, international certification system of all kinds of biomass and circular feedstocks

Type of Framework: Certification System | Policy | Standard

Operating/ in force since: 2010

Legally Binding: ✕ | ✓

ISCC PLUS by ISCC International Sustainability & Carbon Certification

Circular and Bio-circular materials, mass balance approach. Market leader – the ISCC allows brand owners and retailers to use the ISCC logo and communicate related claims. The ISCC certification approach requires the the entire upstream supply chain to be ISCC certified (only FSC with CoC accepted).

Products Covered
Circular materials, bio – and bio circular materials. Biogenic -, direct air capture - and post-industrial (fossil) CO2

Industry Uptake: Certificated products: 65,849 including, over 500 polymer certificates an around 10 CO_2 based materials

SUPPORTING THE CIRCULAR ECONOMY ISCC CERTIFIED

Table 18: Mapping of relevant sustainability criteria for biomass covered by ISCC PLUS

Environmental criteria		Land criteria	
Reduce GHG emissions	X	Increase carbon stock on land / Exclude land with high carbon stock	X
Protection of air soil and water	X	Take measures to maintain and improve biodiversity	X
Waste usage and reduction	X	Create and apply a sustainable forest management plan	FSC
		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	X
Social aspects		**Social aspects**	
Compliance with human rights	X	Compliance with land rights	X
Compliance with labour rights	X	Compliance with water rights	X

Additional Criteria – ISCC PLUS

Environmental criterion: "Each farm/plantation shall provide a plan appropriate to the scale and intensity of operations to reduce air pollution and greenhouse gas (GHG) emissions.
Environmental criterion: Application of good agricultural practices to reduce water usage and to maintain and improve water quality
Environmental criterion: Best practices in plant production product application
Environmental criterion: ISCC Principle "Circular Economy" encourages companies to incorporate waste materials into their production processes
Land criterion: Avoidance of damage or deterioration of habitats
Land criterion: Natural vegetation areas around springs and natural watercourses maintained or reestablished (y/n)
Social criterion: Social criteria add-on under ISCC PLUS (best-practice requirement): Employment relationships

REDcert² Chemistry

Germany-based certification system of all kinds of biomass and circular feedstock

Type of Framework: Certification System | Standard | Policy

Operating/ in force since: 2018

Legally Binding: ✗ | ✓

REDCert² Chemistry by REDCert GmbH

REDcert² scheme for the certification of sustainable material flows in the chemical industry also allows the use of biomass and recovered materials for chemical and mechanical recycling. Focus former on fuels and bio-based feedstocks. Planned to focus more on materials with the REDcert² Chemistry scheme. The distinction between pre/post-consumer waste is optional, but possible. The REDcert² certification accepts following schemes in the value chain: ISCC PLUS, RSB, EUCertPlast and RecyClass

Products covered

Use of biomass covers also CO_2 based materials. Recycled materials cover processing and final products but also licencing is allowed for automobile and brands. The minimum quantity for the substitution of fossil raw materials with renewable raw materials is 20 % (recycling is also a renewable raw material), the actual duration is specified in the individual certificate.

Products covered

Ca. 2000 companies are certified, every company has only one group certificate, certificates for 76 companies for the REDcert² for chemical industry includes group certificates with large number of different kind of items which enhance the number of certificates.

Table 19: Mapping of relevant sustainability criteria for biomass covered by REDcert²

Environmental criteria		Land criteria	
Reduce GHG emissions	–	Increase carbon stock on land / Exclude land with high carbon stock	X
Protection of air soil and water	–	Take measures to maintain and improve biodiversity	–
Waste usage and reduction	X	Create and apply a sustainable forest management plan	Not applicable
		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	Use SAI/FSC/ PEFC
Social aspects		**Social aspects**	
Compliance with human rights	X	Compliance with land rights	–
Compliance with labour rights	X	Compliance with water rights	–

Additional Criteria – REDcert²

Environmental criterion: In the production or purchasing process of a biomass-based product certified under the REDcert² scheme at least 20% of the fossil-based raw material used to produce this product has been replaced by an equivalent amount of sustainably certified biomass in integrated production sites or facilities or within the scope of the extended mass balance.

RSB – Roundtable on Sustainable Biomaterials

Switzerland-based, international certification system of all kinds of biomass and circular feedstocks

Type of Framework: **Certification System** / Standard / Policy

Operating/ in force since: 2013

Legally Binding: ⊗ / ⊗

RSB – Roundtable on Sustainable Biomaterials

RSB certification is a globally recognized sustainability framework for biomaterials, biofuels, and biomass production. It is considered the world's most trusted and peer-reviewed certification standard in this field. RSB recognises other credible certification standards and as well as national requirements and practices for sustainability thus facilitating certification for companies. Supply chains can begin at the stage of feedstock production, or in the case of waste and residue-based chains, at the Point of Origin, no self declaration for farms.

Products Covered

RSB certificates are applicable to a wide range of products and industries. The eligible products for RSB certification include Advanced Products (non-energy products from sustainable supply chains). Bio-based or recycled fossil feedstocks as well as CO^2 based materials, they are certified under advanced feedstocks and as recycled carbon.

Industry Uptake: Around 100 certificates, 40 which of are at the moment vaild. Most of the certified materials are bio-based, only very few other certificates.

Table 20: Mapping of relevant sustainability criteria for biomass covered by RSB

Environmental criteria		Land criteria	
Reduce GHG emissions	X	Increase carbon stock on land / Exclude land with high carbon stock	X
Protection of air soil and water	X	Take measures to maintain and improve biodiversity	X
Waste usage and reduction	X	Create and apply a sustainable forest management plan	Use FSC
		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	X
Social aspects		**Social aspects**	
Compliance with human rights	X	Compliance with land rights	X
Compliance with labour rights	X	Compliance with water rights	X

Additional criteria – RSB

Environmental criterion: Air management plan: Major air pollutants are identified (y/n) &Description of any mitigation measures is provided (y/n)

Environmental criterion: Waste and co-products are used for energy generation, unless material purpose is possible (y/n)

Environmental criterion: Good practices include: Measures to ensure rain water capture, irrigation storage and delivery systems, water-saving practices

Land criterion: Implement practices to protect soil structure

Land criterion: Method to determine low iLUC-risk count: Certification Body Reporting Tool

Social aspects: In regions of poverty, the socio-economic status of local stakeholders impacted by the operations shall be improved.

Social aspects: Operations shall assess risks to food security in the region and locality and shall mitigate any negative impacts that result from their operations.

RSPO – Roundtable on Sustainable Palm Oil

Dedicated certification scheme for one of the most contested bio-based feedstocks worldwide

Type of Framework: Certification System | Policy | Standard

Operating/ in force since: 2004

Legally Binding: ✗ | ✓

Raw Material Covered

RSPO Certification assures individuals that RSPO Members who produce or physically handle RSPO Certified Sustainable Palm Oil (CSPO) and have obtained RSPO Certification.

Products Covered

Palm oil or palm oil derivatives certified by the RSPO can be sourced through four different supply chain models: Identity Preserved, Segregated, Mass Balance and RSPO Credits / Book and Claim.

Table 21: Mapping of relevant sustainability criteria for biomass covered by RSPO

Environmental criteria		Land criteria	
Reduce GHG emissions	X	Increase carbon stock on land / Exclude land with high carbon stock	X
Protection of air soil and water	X	Take measures to maintain and improve biodiversity	–
Waste usage and reduction	–	Create and apply a sustainable forest management plan	Not applicable
		Restrict the use of high iLUC-risk feedstock and enhance use of low iLUC-risk feedstock	–
Social aspects		**Social aspects**	
Compliance with human rights	X	Compliance with land rights	X
Compliance with labour rights	X	Compliance with water rights	X

Additional criteria – RSPO

Environmental criterion: Implement buffer zones and ecological corridors

Land criterion: RSPO manual on best management practices for management and rehabilitation of peatlands

Social aspects: Stakeholder equity (especially for women and affected communities)

Annex IV – Excursus: Bio-based carbon: Long-term or short-term application?

Should the potential quotas be the same for short- or long-living applications? Some policy proposals advocate the use of biobased plastics for short-term applications only, while others argue that, from a climate perspective, there is no difference between short- and long-term applications. Packaging is usually a short-term application, whereas in other sectors, such as automotive and construction, applications are almost always long-term. The following segment will discuss the different views, frameworks and impacts of product lifespan.

Longevity of products is fundamentally valuable for carbon storage – regardless of the carbon source.
Extending the lifespan of products, or manufacturing long-lived products, can keep carbon locked away from the atmosphere for longer periods. For **fossil-based products**, this longevity delays emissions, effectively buying crucial time for climate mitigation efforts. For **bio-based products**, longevity directly translates into **Carbon Dioxide Removal (CDR)**, acting as negative emissions during the storage period. While maximising lifespan is not feasible for all applications (e.g. food packaging), prioritising longevity wherever possible enhances a product's climate benefit.

Bio-based materials offer substantial advantages for climate and nature.
When sourced and managed responsibly, bio-based products can deliver significantly lower lifecycle emissions than their fossil counterparts[2]. This is because they enable the vital substitution of fossil carbon. Life Cycle Assessments (LCAs) consistently demonstrate this potential[3]. Crucially, sufficient biomass exists *globally* to support such uses, but this requires **strict sustainability safeguards** – protecting biodiversity, ensuring responsible land use (avoiding ILUC), and meeting social criteria. Effectively mitigating climate change through sustainable bio-based solutions in turn contributes to biodiversity conservation.

Combining bio-based carbon with long-term storage does not lead to *additional* systemic climate benefit.
The core advantages of bio-based carbon (reducing CO_2 emissions) and long-term storage (extending duration of carbon sequestration) are distinct and largely separable. While a long-lived bio-based product *does* provide valuable CDR for its lifespan, there is no *extra* or multiplicative climate benefit gained *systemically* simply from combining the “bio-based” and “long-lived” attributes beyond what each contributes individually. The primary systemic benefits remain substitution and the duration of storage/removal.

A key consideration is the difference between product perspective and systemic perspective. While a product-level view (via life cycle assessment, or LCA) might show a long-lived product achieving negative carbon footprints by storing biogenic carbon, from a systemic standpoint, there is no net climate benefit as long as biogenic carbon remains a limited resource. If limited biogenic

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[2] https://publications.jrc.ec.europa.eu/repository/handle/JRC127868

[3] A typical greenhouse gas (GHG) emission reduction is about 30%. Taking the latest updates to fossil emissions into account (e.g. in ecoinvent), this figure rises to about 40%.

carbon is targeted to be used in a specific sector, it is no longer available (or more expensive) as a renewable substitute for another sector. This means, fossil carbon is simply shifted to another area without reducing total emissions.

At the systemic level, the industrial use of limited biomass for products with long-term storage should not be prioritised as long as we continue to use fossil carbon in significant quantities in short-lived products.

If fossil carbon remains dominant in products with short lifespans (like food packaging) their carbon is rapidly released into the atmosphere. Therefore, the most impactful use of limited sustainable biomass resources is to **displace these immediate fossil emissions**. Allocating biomass instead to long-term storage applications – although valuable for CDR – may be less strategically urgent than tackling the larger, more immediate problem: the constant stream of emissions from fossil-based short-lived products. Prioritising biomass for substitution in these high-turnover sectors delivers faster near-term emission reductions and facilitates carbon circularity.

In this context, it should be noted that short-lived products such as packaging have a particularly large impact when it comes to greenhouse gas (GHG) savings through the substitution of fossil-based plastics with bio-based plastics. Due to their relatively short lifespan, fossil-based plastics emit significantly higher levels of greenhouse gases (GHGs) over for example 35 years than long-lasting products.

Replacing short-lived fossil-based plastics with bio-based alternatives therefore results in a greater reduction in greenhouse gases over a given time period than in long-lasting products.

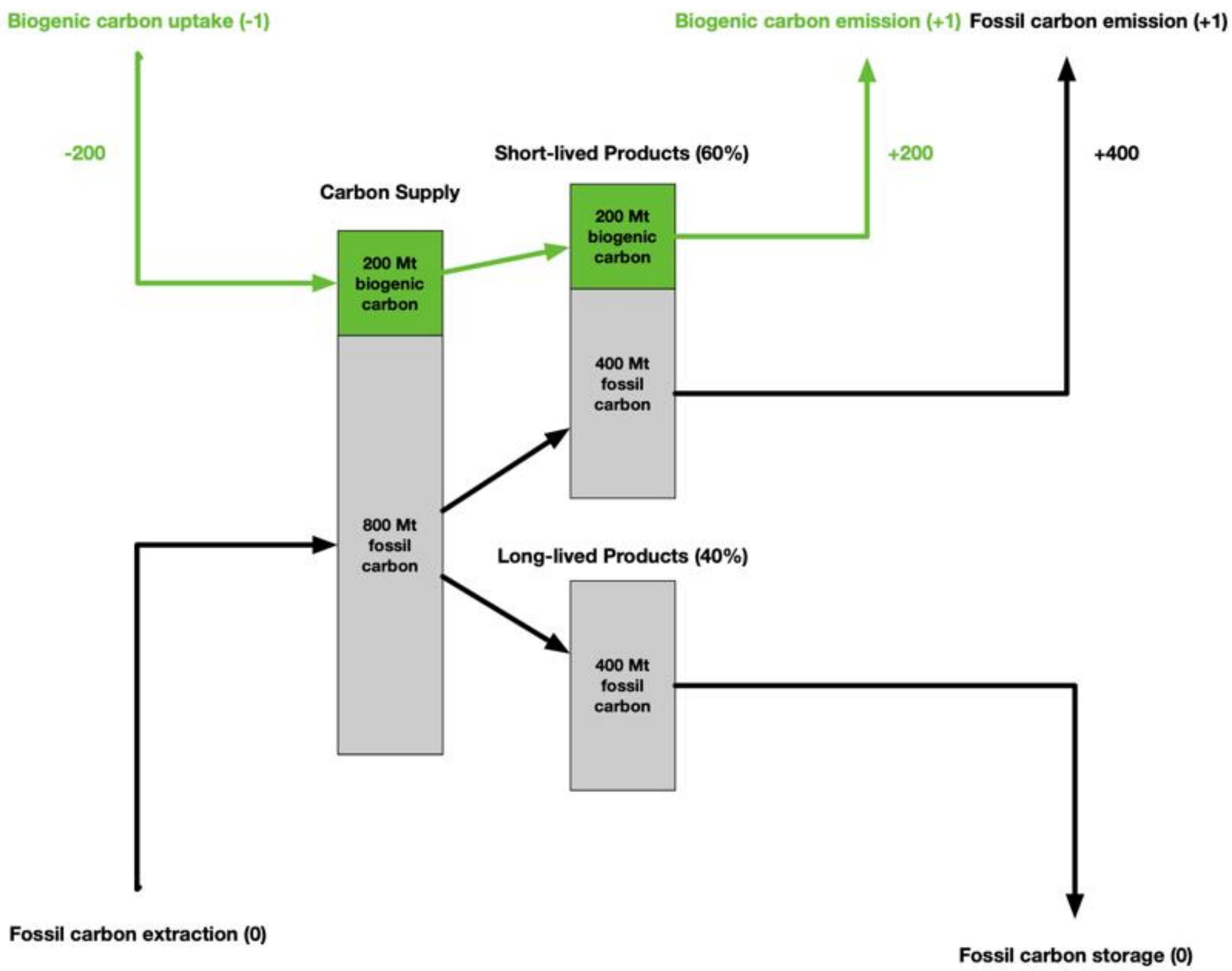
Visualisation in a calculation example of three different scenarios:

A total carbon demand of 1,000 Mt is covered by fossil-based (80%) and bio-based (20%) carbon. Of the 1,000 Mt overall carbon demand, 600 Mt ends up in short-lived products, while 400 Mt end up in long-lived products. Short-lived products are assumed to cause emissions at end-of-life, while long-lived products are assumed to keep the carbon bound for a climate-relevant duration period, effectively allowing to account for carbon storage. Independent of the distribution of bio-based carbon, systemic GHG emissions always stay the same, as potential biogenic carbon storage in long-lived products is countered by additional fossil carbon emissions in short-lived products.

Table 22: Calculation examples for fictitious scenarios of bio-based carbon directed towards long- or short-lived products.

Carbon share	Scenario	Demand Short-lived	Bio-based	Fossil-based	Demand Long-lived	Bio-based	Fossil-based	Systemic GHG Emissions	
Fossil-based: 80% Bio-based: 20%	All bio-based into **Short**	600	200	400	400	0	400	400	(400 fossil-based)
	All bio-based into **Mixed**	600	100	500	400	100	300	400	(500 fossil - 100 biogenic storage)
	All bio-based into **Long**	600	0	600	400	200	200	400	(600 fossil - 200 biogenic storage)

Graphical visualisation of scenario 1 (all bio-based carbon directed into short-lived products):

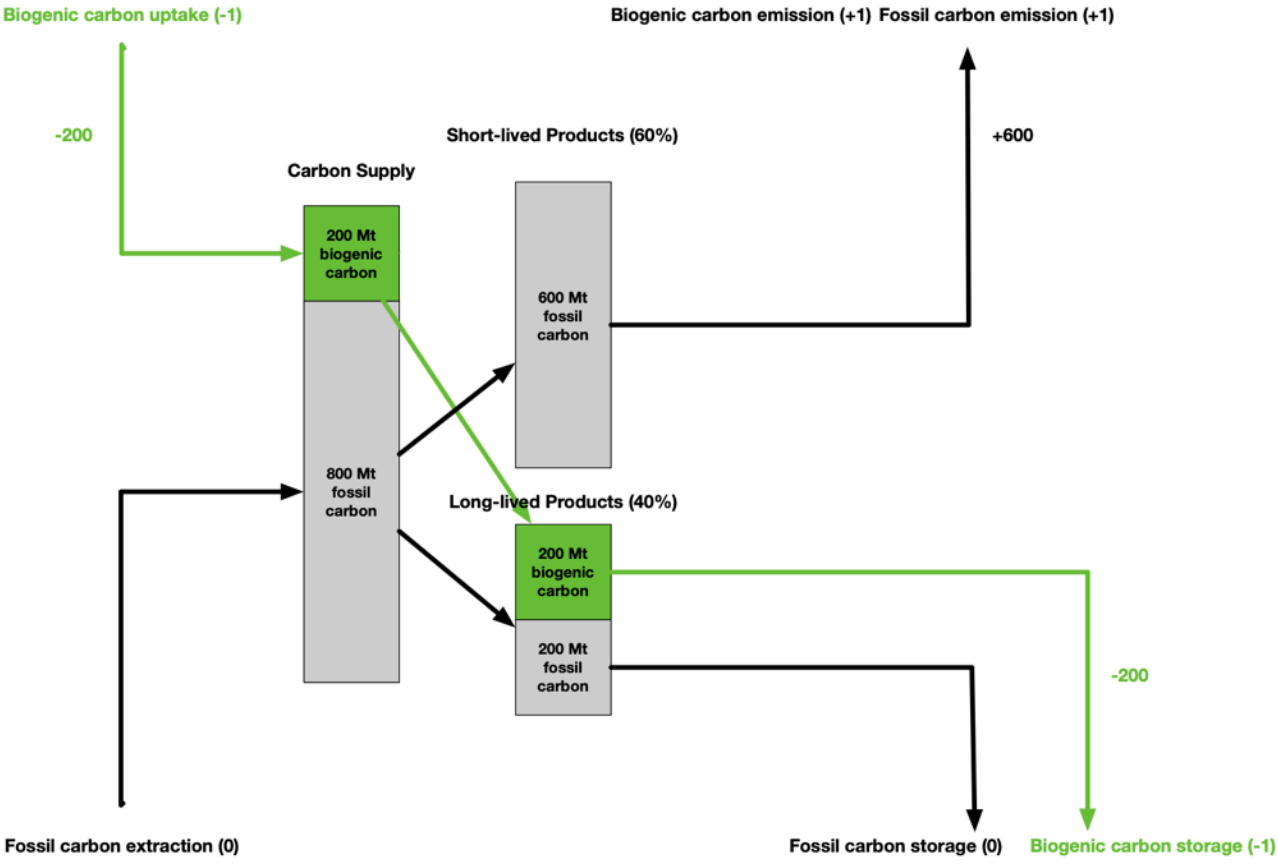


200 Mt biogenic carbon uptake, of which 200 Mt are released at End-of-Life (EoL) of short-lived products (= 0 Mt of biogenic C emissions, since uptake and emission balance out)

800 Mt fossil carbon extracted, of which 400 Mt are released at EoL of short-lived products (= 400 Mt of C into emissions) and 400 Mt are stored away for a climate-relevant duration in long-lived products (= 0 Mt of C into emissions).

Total: 400 Mt of fossil emissions – 0 Mt of biogenic storage = 400 Mt carbon emissions

Graphical visualisation of scenario 2 (all bio-based carbon directed into long-lived products):

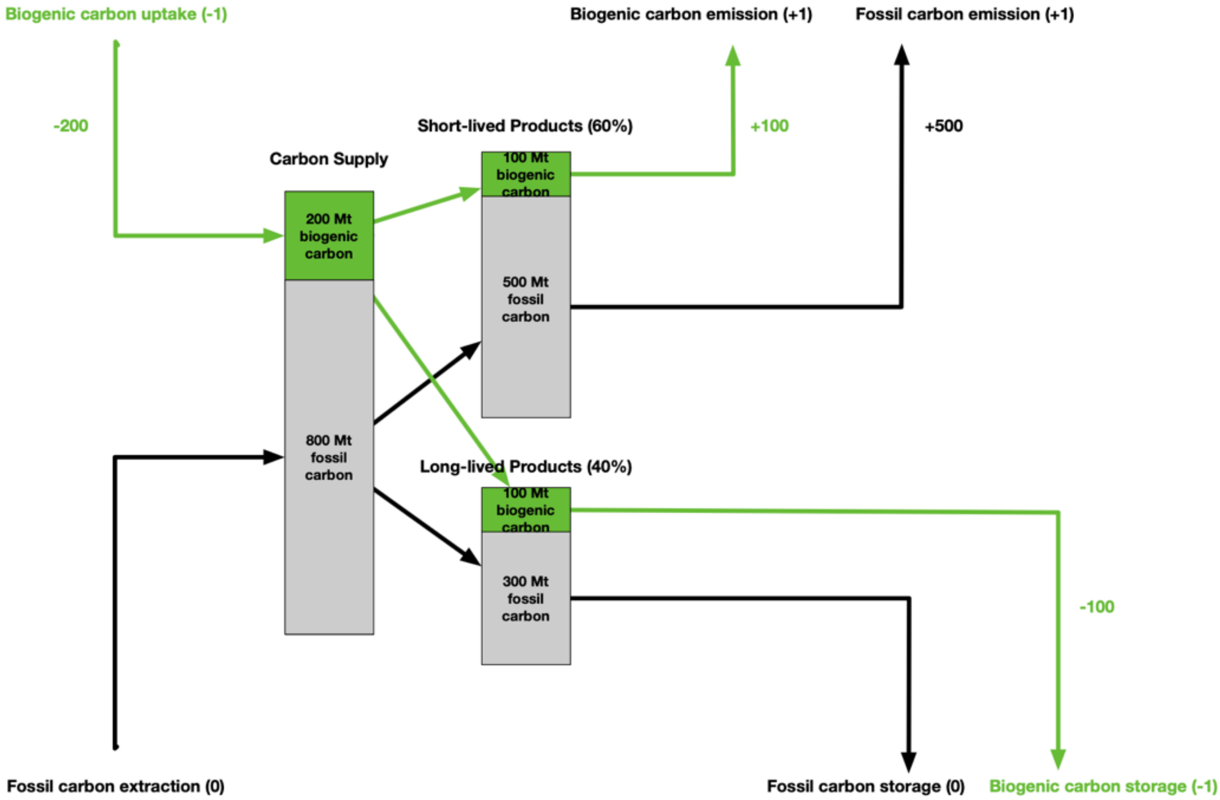


200 Mt biogenic carbon uptake, of which 200 Mt are stored away for a climate-relevant duration in long-lived products (= -200 Mt C into emissions)

800 Mt fossil carbon extracted, of which 600 Mt are released at EoL of short-lived products (= 600 Mt C into emissions) and 200 Mt are stored away for a climate-relevant duration in long-lived products (= 0 Mt emissions).

Total: 600 Mt of fossil emissions – 200 Mt of biogenic storage = 400 Mt carbon emissions

Graphical visualisation of scenario 3 (bio-based carbon mixed distribution into products):



200 Mt biogenic carbon uptake, of which 100 Mt are released at EoL of short-lived products (= 0 emissions, uptake and emission balance balance out) and 100 Mt are stored away for a climate-relevant duration in long-lived products (= -100 emissions)

800 Mt fossil carbon extracted, of which 500 Mt are released at EoL of short-lived products (= 500 Mt C into emissions) and 300 Mt are stored away for a climate-relevant duration in long-lived products (= 0 Mt emissions).

Total: 500 Mt of fossil emissions – 100 Mt of biogenic storage = 400 Mt carbon emissions

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