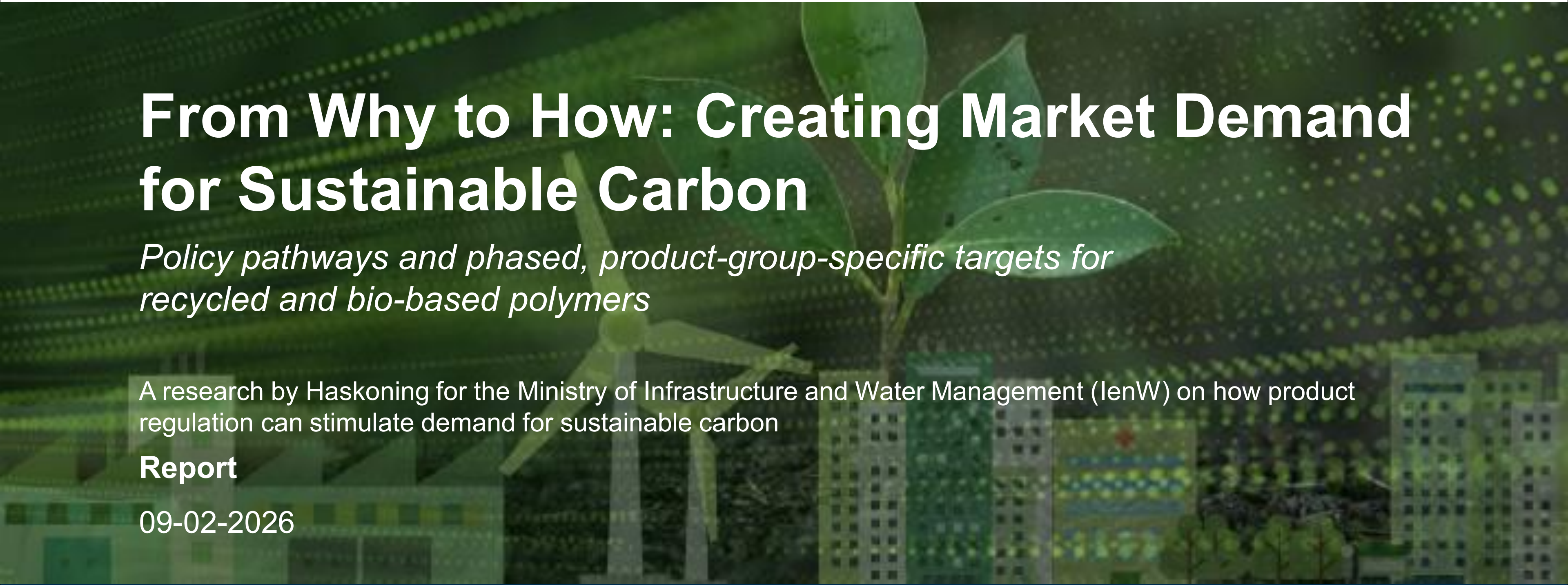


From Why to How: Creating Market Demand for Sustainable Carbon

Policy pathways and phased, product-group-specific targets for recycled and bio-based polymers

A research by Haskoning for the Ministry of Infrastructure and Water Management (IenW) on how product regulation can stimulate demand for sustainable carbon

Report

09-02-2026

Introduction

This study focuses on how product regulation can stimulate demand for sustainable carbon

From Why to How: Creating Market Demand for Sustainable Carbon

Why

The main driver for stimulating the use of sustainable carbon in the chemical industry is the **development of market demand**.

This need has been clearly articulated in policy visions and previous studies, highlighting the importance of **demand-side incentives** to **accelerate sustainable carbon use**.

How

This study provides guidance for policymakers on **how product regulation can be used and designed** to stimulate demand for chemical products produced using sustainable carbon.

1. What to prioritize - product groups

- Which product groups offer the **greatest potential for sustainable carbon use**?
- Assessment based on **European production volumes**, **carbon content**, **technical readiness**, and **impact of substitution**.

2. Impact of substitution – from fossil to sustainable polymers

- What are the potential **economic and environmental impacts** of replacing fossil carbon with sustainable carbon in these product groups?
- Assessment of both **recycled** and **bio-based** alternatives for fossil polymers.

3. Where to intervene - regulation

- Where in the **regulatory landscape** can policy intervention be most effective?
- Identification of concrete **European legal and regulatory entry points** for each priority product group.

Scope implications

In this study, the potential impact of a sustainable carbon target is explored for a limited **selection of fossil and alternative polymers base**d on **European production volumes** and the **TRL of sustainable alternatives**. The potential contribution of sustainable polymers not included in this selection should not be disregarded.

The results indicate that a **mandatory target on sustainable carbon content** has the potential to function as an **effective and workable demand-side instrument**.

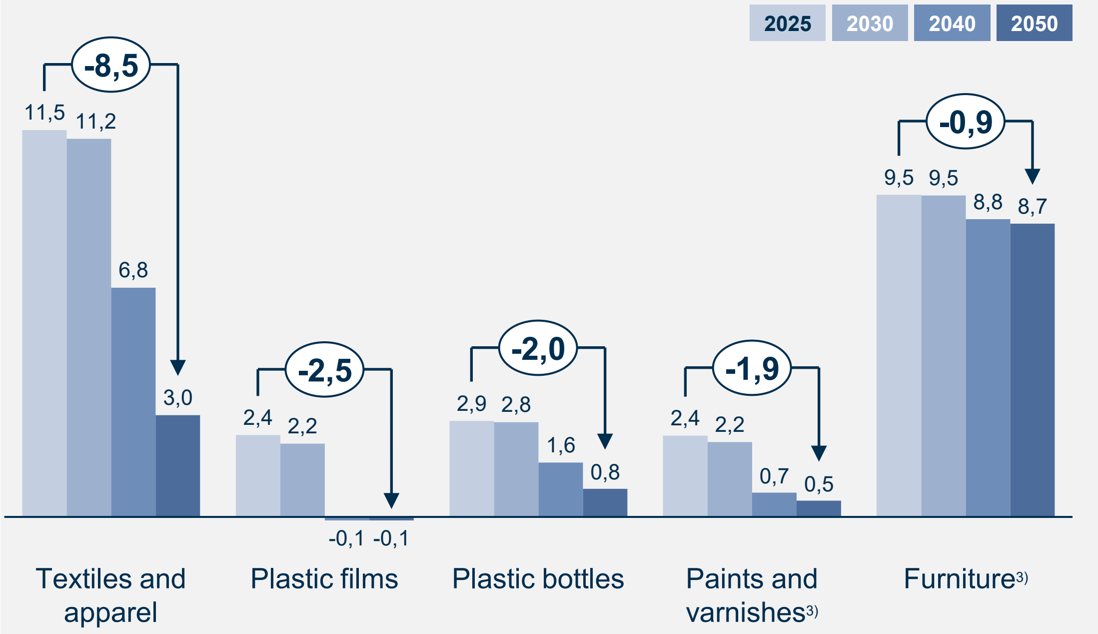
The assessments in this study are exploratory and do not capture the full economic and environmental impacts of mandatory targets within specific product groups. **Further research** is required to strengthen the evidence base **prior to considering legislative implementation**. This should include both deeper assessment of the polymers analyzed in this study and an extension of the analysis to additional fossil and sustainable polymers.

Executive Summary

Policy should prioritize sustainable carbon substitution in textiles and packaging, as these offer the largest potential for climate impact reduction in European production

Potential climate change impact of European production per product group[1] in 2030, 2040 and 2050, Mt CO_2 equivalent

Climate change impact per product group per year[2] [Mt CO_2 eq.]



Conclusions

Prioritization of product groups:

- **Textiles and packaging should be prioritized for sustainable carbon substitution** as these product groups show the largest potential climate impact reduction and already fall within the priority scope of the **ESPR**, enabling fast implementation.
  - **Within packaging,** plastic films and bottles can and should be addressed separately under the **PPWR**.
- For **paints & varnishes and furniture**, the sustainable alternative polymers have **lower technological readiness**, limiting substitution potential in the short to medium term. These product groups should therefore receive **lower policy priority.**

Mandatory targets for sustainable carbon content:

- Recycled and bio-based polymers play **complementary roles** in replacing fossil carbon **across products and value chains,** while facing **different limitations,** making both necessary rather than interchangeable in the transition to sustainable carbon use.
- **Mandatory targets for sustainable carbon** content can provide a clear **demand-side signal** to actively support both pathways and accelerate new technologies and market development.
- From a transition perspective, **mandating recycled and bio-based content separately** may be preferable, as it helps safeguard investment in bio-based alternatives alongside recycling.

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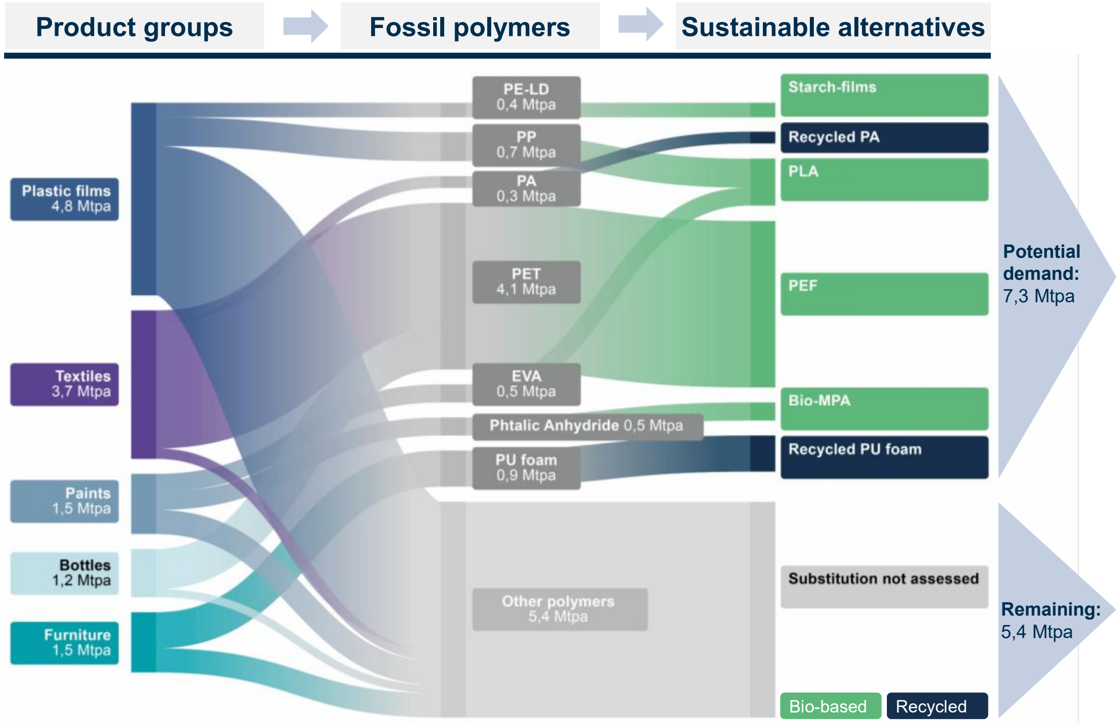
1) These results are based on substitution between the fossil and sustainable alternative polymers assessed in this study and account for biogenic carbon uptake in biobased polymers. The estimated climate change impacts per product group are derived from an initial, indicative assessment and are intended to support policy discussion. Further research is required to validate and refine these estimates.
2) These climate change impacts are calculated using current production volumes in the EU and the targets determined by the economic impact analysis. 3) These climate change impacts are conservative estimations due to lack of credible data.

This study covers six sustainable alternatives as substitutes for seven fossil polymers across five priority product groups, creating a potential demand[1)] of up to 7,3 Mtpa

Assessed product groups, fossil polymers and sustainable alternatives and their associated volumes in Mt per annum (Mtpa)



Scope and coverage of this study

This study assesses **six sustainable alternatives** as substitutes for **seven fossil polymers** across **five priority product groups**, with high potential for sustainable carbon replacement**.**

This selection is based on **European production volumes of the product groups**[2)] and a **multi-criteria decision-making framework.**

The multi-criteria decision-making framework is used to determine a weighted score for each sustainable alternative considering three criteria:

- The potential for environmental impact reduction;
- The costs for the consumer;
- Technological Readiness Level (TRL) of the alternative.

The selected alternatives include **four bio-based polymers** and **two recycled polymers**.

Implications for impact potential

The remaining 5,4 Mtpa of polymers consists of small volume flows or polymer applications where substitution faces hurdles[3].

Applying substitution targets beyond the assessed polymers will result in **additional demand creation** and likely in further **environmental impact reductions.**

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1) This potential demand reflects a theoretical maximum demand with complete substitution of the assessed polymers.
2) The European production volumes of the product groups are measured by the fossil carbon content volume in Mt per annum.
3) Hurdles such as restrictive legislation or material requirements.

Mandatory targets can scale sustainable carbon demand, but effectiveness depends on clear choices between combined or separate targets, and a robust LCA methodology

Key considerations for effective EU demand creation for sustainable carbon

Economic

- **Mandatory targets for sustainable carbon content establish demand certainty**, reducing market risk and enabling market uptake of sustainable polymers while limiting additional costs for consumers. This helps create the **economic preconditions for viable business cases** and encourages early investment. However, **target design will determine how investment is directed across technologies.**
    - **Combined targets risk favoring lower-cost recycled polymers** and may delay investment in bio-based alternatives.
    - **Separate targets** for bio-based and recycled content, provided the right conditions and framework are in place to implement and enforce them, could **strengthen business cases for bio-based polymers**, which typically have higher production costs. Guaranteed demand would **accelerate economies of scale** and ultimately reduce costs.
- Sustainable polymer production becomes **commercially viable** only once a critical **minimum market scale** is reached; targets must therefore be sufficiently ambitious to create scale and provide long-term investment certainty. **A phased introduction is needed** to allow industry to adapt production processes before scaling to full market potential.

Environmental

- A clear methodological choice is required to **enable fair LCA-based comparison of fossil-based, recycled and bio-based polymers**, as the existing approach does not yet fully capture the **environmental impacts for bio-based** polymers.
- **Policymakers will need to decide on the most inclusive methodology to ensure comparable impact claims**, for example by using approaches such as the **+1/–1 method** to reflect the positive effects of bio-based polymers **without classifying them as carbon sinks**[1]. **Further research is required** to support this choice, including how to account for impacts such as **land use and microplastics**.
- The environmental impacts of bio-based polymers depend on **feedstock sourcing and agricultural practices**. Achieving environmental benefits therefore requires **responsible biomass** sourcing and appropriate land-use safeguards. This should be supported by deliberate policy and market design.

Policy

- Effective stimulation of sustainable carbon use requires an **integrated policy framework**, aligning target-setting, impact assessment methodologies, legislation, and market conditions.
- **Regulatory alignment with parallel EU instruments** is required to avoid conflicting incentives and regulatory fragmentation.
- **The PPWR and ESPR provide concrete legislative entry points** to introduce binding targets for recycled and/or bio-based content **at product-group level**, through foreseen delegated acts, without requiring changes to the core regulatory frameworks.
- The **Bioeconomy Strategy** enables the integration of bio-based targets into existing regulations (PPWR and ESPR) through Ecodesign requirements, with the **Circular Economy Act and Biotech Act 2** further embedding these targets in product-specific legislation.
- **The EU should define clear priorities and measurable, product-group-specific targets for sustainable polymers**, supported by a clear description of product groups. Without explicit targets at product-group level, demand creation and market steering are likely to remain fragmented and ineffective.

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1) A carbon sink is a natural or human-made system that absorbs and stores more carbon dioxide (CO_2) than it releases (e.g. forests, oceans, and soils). However, bio-based polymers should not be classified as carbon sinks, since the associated biogenic carbon forms part of the short-term carbon cycle.

This study integrates economic, environmental and policy analyses of the selected five priority product groups to assess their potential for sustainable carbon replacement

Table of contents

In this study the following abbreviations are used frequently

Overview of abbreviations

Bio-MPA	Bio-based maleic phthalic anhydride
CBAM	Carbon Border Adjustment Mechanism
CEAP	Circular Economy Action Plan
CED	Cumulative Energy Demand
CO_2-eq	Carbon dioxide equivalent
CTUe	Comparative Toxic Unit for ecosystems
EPR	Extended Producer Responsibility
EVA	Ethylene Vinyl Acetate
ESPR	Ecodesign for Sustainable Products Regulation
ETS	Emissions Trading System
EU	European Union
FDCA	Furan dicarboxylic acid
FMCG	Fast-Moving Consumer Goods
IPCC	Intergovernmental Panel on Climate Change
Ktpa	kilotons per annum
LCA	Life Cycle Assessment
LDPE / PE-LD	Low-Density Polyethylene
MEG	Mono-ethylene glycol
MJ	Megajoule
Mt / Mtpa	Megatons / megatons per annum
PA, rPA	Polyamide, recycled PA
PEF	Polyethylene Furanoate
PET, rPET	Polyethylene Terephthalate, recycled PET
PLA	Polylactic Acid
PM	Particulate Matter
PP	Polypropylene
PPWR	Packaging and Packaging Waste Regulation
Pt	Points (land-use indicator unit)
PU, PUR	Polyurethane, PU Foam
TRL	Technology Readiness Level

A

Selection of priority product groups with high potential for sustainable carbon replacement

Based on a multi-criteria decision-making framework, five product groups linked to eight fossil – sustainable polymer couples are selected for further analysis

Overview of selected product groups and fossil – sustainable polymer couples

Product groups	Fossil - sustainable polymer couples	
Plastic films, sheets and foils (packaging)	**Starch** as a substitute for PE-LD	**PLA** as a substitute for PP
Plastic bottles and containers (packaging)	**PEF** as a substitute for PET	
Textiles[1] and apparel	**PEF** as a substitute for PET	**Recycled PA** as a substitute for PA
Paints and varnishes	**Bio-MPA** as a substitute for alkyds (e.g. phthalic anhydride)	**PLA** as a substitute for vinyl (e.g. ethylene vinyl acetate)
Furniture	**Recycled PU** (chemical) as a substitute for PU	

🟦 Recycled

🟩 Bio-based

Selection framework

The selection of product groups and sustainable polymer alternatives is made using a combined volume and multi-criteria analysis[2].

Product groups
The considered product groups are assessed on their **production volumes** within Europe. Specifically, their fossil polymer content to identify where material substitution could have the largest impact.

Fossil – sustainable polymer couples
For each fossil polymer, different sustainable alternatives, including both bio-based and recycled polymers, are **qualitatively assessed on three criteria**:

1. **Potential for environmental impact reduction:** how much the alternative can lower carbon emissions.
2. **Costs for the consumer:** considering whether substitution would make products more expensive.
3. **Technological readiness**: how close the sustainable alternative is to large-scale commercial application.

Results
Using this selection framework, five key product groups are identified that offer the most potential for sustainable carbon replacement.

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[1] Textiles includes a broad range of applications beyond clothing, including use in furniture, medical and protective equipment, buildings, and vehicles.
[2] See appendix A for the elaborated version of this selection process.

Based on a multi-criteria decision-making framework, five product groups linked to eight fossil – sustainable polymer couples are selected for further analysis

Results of the multi-criteria decision-making framework

Industry	Product group	Fossil carbon content volume (Mt)	Fossil polymer (largest content in product group)	Sustainable alternative	Multi-criteria decision-making framework			
					Environmental impact	Costs	Technological readiness	Total weighted score[2]
					Weight[1]: 2/3	Weight: 2/3	Weight: 1/3	
Packaging	Plastic films, sheets and foils	4,8	PE-LD	Starch	3 🟢	2 🟠	3 🟢	**13**
			PP	PLA	3 🟢	2 🟠	2 🟠	**12**
	Plastic bottles and containers	1,2	PET	PEF	3 🟢	2 🟠	2 🟠	**12**
Textiles	Textiles and apparel	3,7	PET	PEF	3 🟢	2 🟠	2 🟠	**12**
			PA	Recycled PA	3 🟢	3 🟢	3 🟢	**15**
Chemicals	Paints/varnishes based on polymers	1,5	Phthalic Anhydride	Bio-MPA	3 🟢	3 🟢	1 🔴	**13**
			EVA	PLA	3 🟢	2 🟠	2 🟠	**12**
Houseware, leisure and sports	Furniture	1,5	PU foam	Recycled PU foam	2 🟠	2 🟠	1 🔴	**9**

Legend 🟢 Favorable 🟠 Neutral 🔴 Unfavorable

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1) The weighting system assigns Environmental Impact and Costs twice the importance compared to Technological Readiness in the total weighted score. This prioritization reflects the project's primary goal: to stimulate demand, strengthen business cases, and drive improvements in technological research.

2) The total score is calculated by multiplying each indicator's weight by its respective score and then summing the results for all three indicators

B Economic impact analysis

Sustainable polymer targets[1] can be implemented for the selected product groups without causing feedstock bottlenecks or a significant cost impact on end users.

Results of the economic impact analysis

Industry	Product group	Total fossil content in group	Substituted fossil polymer	Sustainable alternative	Economic impact results			
					Demand[2]	Feedstock	Target viability	End user costs
Packaging	Plastic films, sheets and foils	4,8 Mtpa	PE-LD	Starch (film)	0,4 Mtpa	🟢	🟢	🟢
			PP	PLA	0,7 Mtpa	🟢	🟢	🟢
	Plastic bottles and containers	1,2 Mtpa	PET	PEF	1 Mtpa	🟢	🟢	🟢
Textiles	Textiles and apparel	3,7 Mtpa	PET	PEF	3,1 Mtpa	🟢	🟢	🟢
			PA	Recycled PA	0,3 Mtpa	🟠	🟢	🟢
Chemicals	Paints/varnishes based on polymers	1,5 Mtpa	Phthalic Anhydride	Bio-MPA	0,5 Mtpa	🟠	🟢	🟢
			EVA	PLA	0,5 Mtpa	🟢	🟢	🟢
Houseware, leisure and sports	Furniture	1,5 Mtpa	PUR (PU foam)	Recycled PU foam	0,9 Mtpa	🟢	🟢	🟢

🟩 No foreseen problems

🟧 Potential risks

🟥 Significant risk

Take-aways

- A sustainable polymer target[1] on the five product groups can **create substantial demand** for sustainable carbon-based polymers at the beginning of the chain.
- **There are no feedstock constraints** for realistic short-term targets. At full potential, feedstock demand for Bio-MPA and Recycled PA might prove insufficient. Both can reasonably be overcome before targets would reach that level.
- **Low targets are sufficient** to create demand **for viable production capacity,** while giving the industry time to learn to work with new polymers.
- **The cost impact for end users is low** when compared to typical costs of end-use applications. Especially when compared to total household spendings.

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1) In this analysis, a sustainable polymer target is a target percentage of sustainable polymer in respect to total polymer demand in a product group.
2) Theoretical maximum created demand at 100% substitution of the assessed fossil-sustainable polymer couples.

The economic analysis has two components, the market creation assessment and the product impact assessment.

Methodology of the economic impact assessment

Market creation assessment

Goal of the assessment

The purpose of the market creation assessment is to gauge the feasibility of deploying an alternative polymer target to different product groups. Deployment of a target is considered feasible[1] if no substantial feedstock supply constraints are expected, and if a gradual phase in supports the development of a viable market[2].

Approach for assessment

The assessment is performed in several steps.

1. The theoretical maximum created demand is calculated based on total current polymer volume in a product group, and the substitution potential of the seven assessed alternative polymers.
2. The feedstock requirements for the theoretical created demand, and the requirements for a 15% target, are calculated and compared to the global feedstock availability to assess if the feedstock claim is reasonable.
3. The minimum target for a viable market is calculated. A market is considered viable if demand is sufficient to establish 5 ‘minimum viable’ plants.
4. Two target phase-in approaches are discussed and reviewed.

Cost impact assessment

Goal of the assessment

The purpose of the cost impact assessment is to evaluate the anticipated financial implications for end users of implementing an alternative polymer target at a product level. In addition, the assessment examines each product’s contribution to overall demand for alternative polymers.

Approach for the assessment

The cost impact is assessed through multiple steps.

1. An exemplary product for the different product groups is selected.
   The selected products should be common and recognizable.
2. Alternative polymer demand for the selected products is assessed based on a substitution factor of the alternative relative to the conventional polymer.
3. Using the price difference between the conventional polymer and the alternative, the cost impact on the single product is calculated.
4. The resulting cost impact is related to the costs of the end-use of a product, such as sending a package, or a filled cola bottle in a supermarket.

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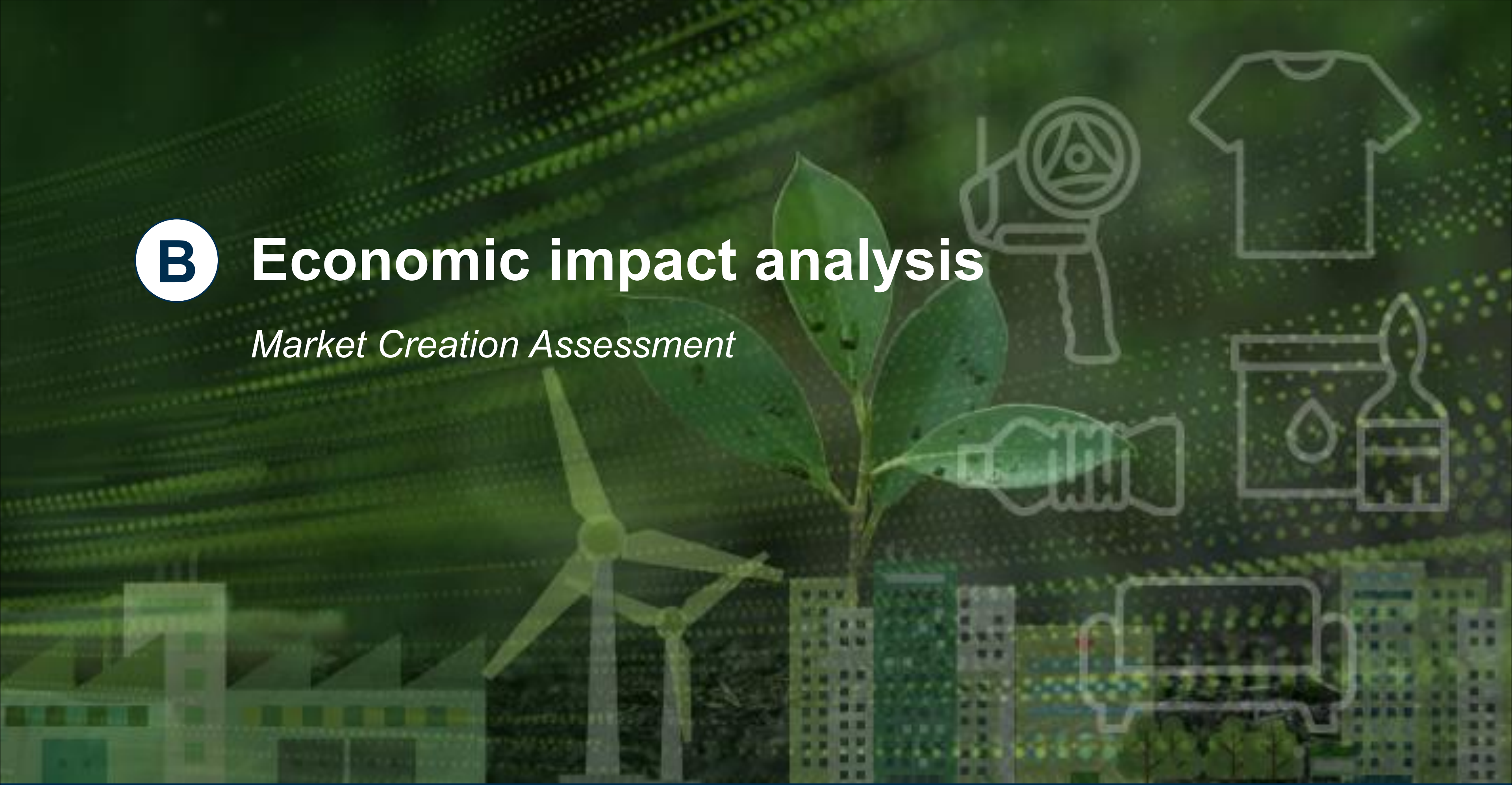
1) There are more factors (investment conditions, environmental compliance, etc) relevant for feasibility of a target, but this is out of scope.
2) A gradual phase in is deemed necessary for a viable market, to minimize disruption, to provide learning time and to minimize risks.

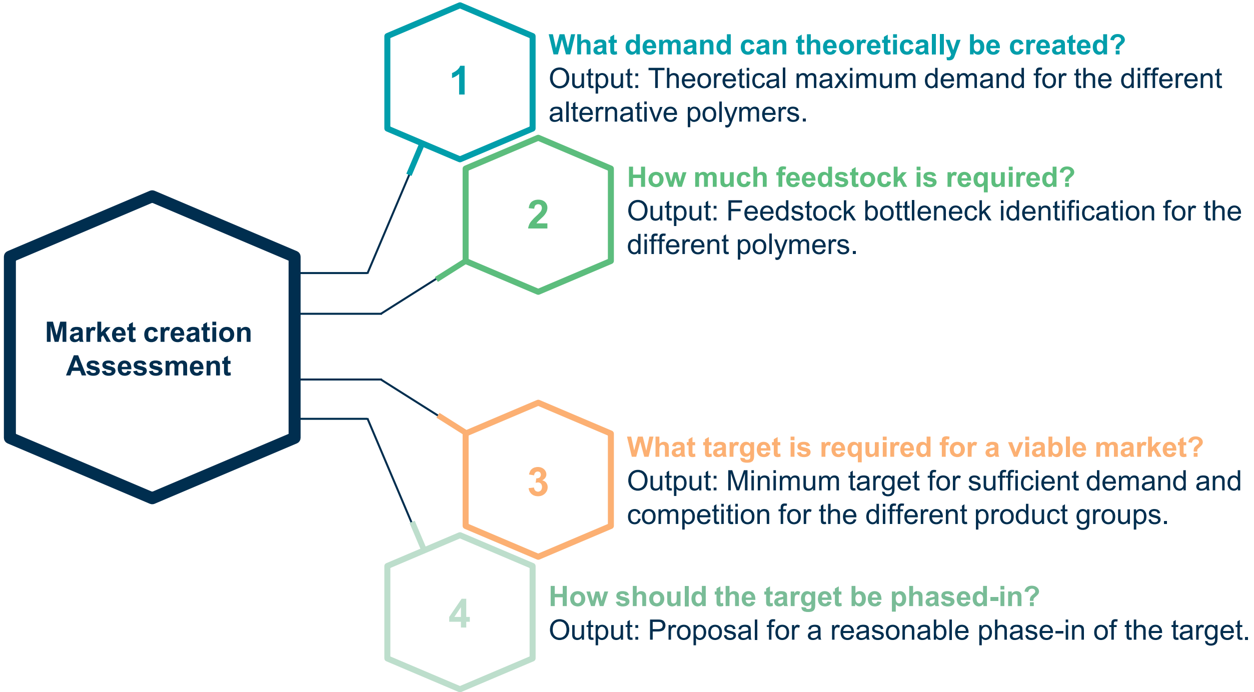


B Economic impact analysis

Market Creation Assessment

The impact of market creation is explored along four axis: potential demand, feedstock requirements, viability, timing effects.

Market creation assessment



Market creation Assessment

1

What demand can theoretically be created?
Output: Theoretical maximum demand for the different alternative polymers.

2

How much feedstock is required?
Output: Feedstock bottleneck identification for the different polymers.

3

What target is required for a viable market?
Output: Minimum target for sufficient demand and competition for the different product groups.

4

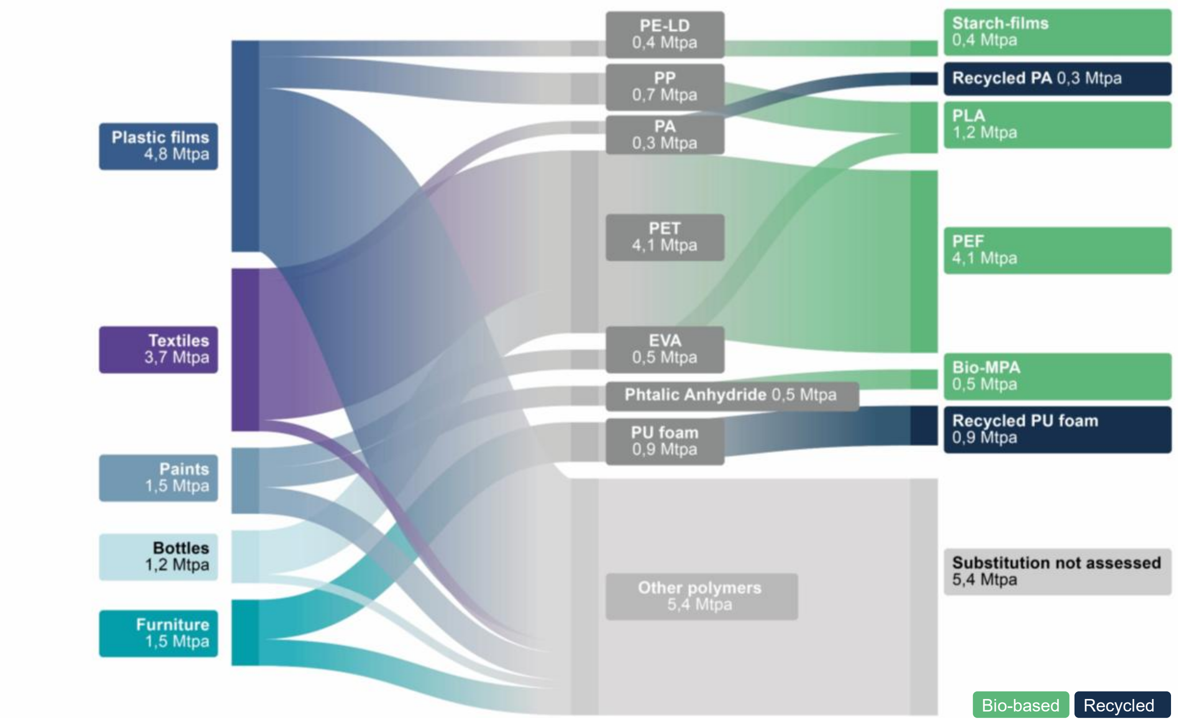
How should the target be phased-in?
Output: Proposal for a reasonable phase-in of the target.

Market creation assumptions

- This assessment is based on the potential impact of an alternative polymer **target on five product groups,** and the substitution of the fossil polymers in these product groups by **the six selected alternative polymers**.
- Possible impact on different alternative polymers, or the impact of a target on different product groups is **out of scope** for this study.

The theoretical maximum substitution of fossil polymers in the five product groups, results in a demand of 7.3 Mton for the six assessed polymers.

What alternative polymer demand can be created?



Comments

- The five product groups result in a maximum **7.3 Mtpa** demand for the assessed alternative polymers, based on an assumed substitution potential. It is assumed that all alternative demand is supplied by the selected fossil-alternative pairs[1)].
- A low and high scenario for the substitution potential results in a demand for alternative polymers of **6.2 – 8.4 Mtpa.**
- The remaining 5.4 Mtpa of polymers consists of small volume flows or applications where substitution polymers have a TRL too low for policy inclusion.
- The analysis concluded that most polymers in the 'plastic films' product group are used in food packaging, excluding them from the scope of this study. Compared to the volumes of this analysis, there is a high potential upside if food packaging can be included in policy.
- This analysis is a snapshot of current consumption profiles and technical possibilities. Change in demand and the emergence of new polymers or recycling technology influence demand and substitution potential.

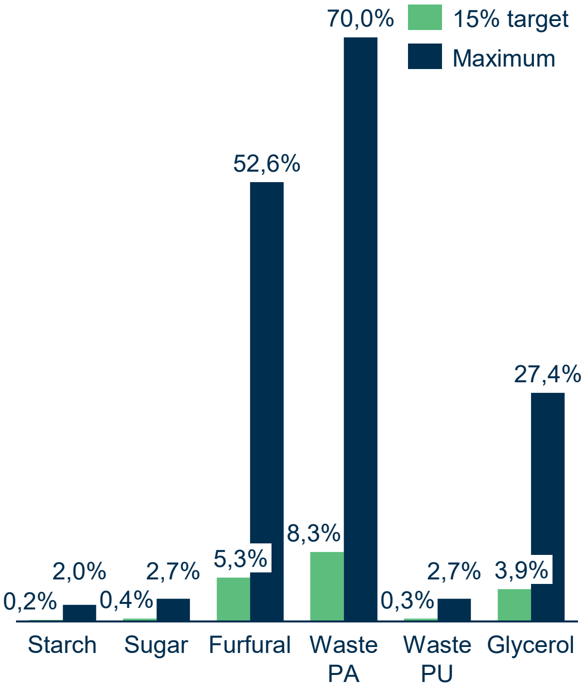
The underlying assumptions and the sensitivity analyses are presented in the appendix.

1) The assessment of only the selected fossil-alternative pairs means that potential positive impact can be higher than projected as some volume flows are not considered. At the same time, it can mean that projected volumes of alternatives are too high as some applications opt for a different alternative (e.g. rPET instead of PEF).

There are no feedstock bottlenecks expected for the early phases of a sustainable polymer target. Recycling and furfural production must increase for full substitution.

How much feedstock is required for the created demand?

Feedstock demand (% of global production)



Feedstock Availability[1)]

Feedstock	Required for	Global production	development	Availability conclusion
Starch	PLA, starch-films	156 Mtpa	Increase	Available
Sugar	PEF	210 Mtpa	Increase	Available
Furfural[2)]	Bio-MPA	1.7 Mtpa	Increase	Production must scale
Waste PA	Recycled PA	3 Mtpa	Increase	Recycling must increase at max target
Waste PU	Recycled PU	41 Mtpa	Increase	Available
Glycerol	PEF	5.3 Mtpa	Increase	Available

Comments

- **Feedstock availability is not a bottleneck** for any polymer at early-phase targets and, while requiring targeted effort, remains **manageable at the theoretical maximum target.**
- Additional demand will compete with other sectors **driving up production, or price.**
- At full 100% substitution the furfural demand rises above 50% of current production capacity, but production can be scaled.
- At the maximum target, waste PA availability poses a risk, but this can be managed by increasing the recycling rate[3)].
- While sugar demand is substantial, its availability is expected to increase. Demand is decreasing in high-income countries due to health concerns. Several European companies with sugars and cellulose in their waste streams are developing processes to recycle or produce sugars, increasing sugar availability.

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1) Sources can be found in in the appendix
2) Furfural is an intermediate product between sugar and several sustainable polymers. It can be bought as commodity or produced locally on-site.
3) Globally 2% of PA (nylon) used is recycled. Materials Market Report 2024 - Textile Exchange

The sustainable polymer targets required for a viable market are low. This benefits producers and consumers as it gives time to experiment with small scale integration.

What minimum target is required for a viable market?

Demand can be created with a sustainable polymer target on a product group. A target sets **the minimum level (%) of sustainable polymer uptake in a group**, in respect to the total polymer volume. A target should increase over time to ensure phase-out of fossil plastics and should start at a 'viable' level where producers can invest, and consumers can learn.

A viable level should be as low as possible to give the market time to develop and integrate new technologies, but high enough to create sufficient demand for a profitable plant size and healthy competition.

In this analysis, a minimum target must create sufficient demand for (1 **at least 1 plant for each different potential alternative polymer** in a group, and (2 **at least 3 plants total to kickstart competition** between sustainable polymer producers.
The 'viable' target calculated for the assessed polymers is then extrapolated to the whole group based on the substitution potential of the assessed polymers. This results in an '**viable product group target'.**

Viable product group target, based on extrapolation of assessed polymers

Product groups	In-scope alt. polymers in group	Minimum targets for 'viable' market[1]	Selected fossil polymers in group[2]	Viable product group target
Plastic films, sheets, plates, foil, strip	Starch (films) PLA	**10%**	**23%**	**2,3%**
Textiles and apparel	Recycled PA PEF	**3%**	**93%**	**2,8%**
Paints and varnishes	PLA Bio-MPA	**9%**	**60%**	**5,4 %**
Plastic bottles and containers	PEF	**2%**	**83%**	**1,7%**
Furniture	Recycled PU	**2%**	**60%**	**1,2%**

Comments

- All product groups **can reach a viable market at a low target level**. Paints are at the high end (roughly 1 in 20 paint cans must be sustainable), and furniture is on the low end (only 1 in 80 sofas needs to be sustainable).
- Globally there are multiple commercially operating Recycled PA, PLA, Starch-film and Recycled PU plants. Here a target would benefit the established market, likely resulting in upscaling capacity of existing facilities instead of the emergence of new plants.
- There are first of a kind production plants for PEF and Bio-MPA. A target would benefit the players operating these plants but would also provide opportunities for new players entering the market.
- This target is only workable on a book-and-claim basis, as blending in plastics changes material characteristics, leaving some applications unable to find an alternative.
- While the assessed polymers are deemed to be the most likely alternatives, it is likely that other alternatives emerge alongside them. When targets are increased, sufficient demand is created to support multiple competing alternative polymers.

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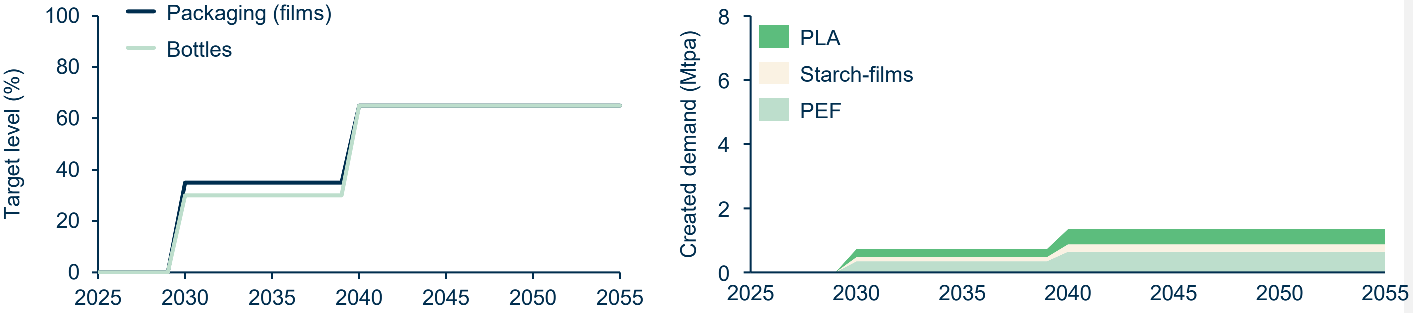
1) Calculated based on typical small commercial plant capacities for the different alternative polymers. The sources are presented in the appendix.
2) These percentages are the volume of the selected fossil polymers in respect to total group volume, as displayed in the theoretical maximum market creation.

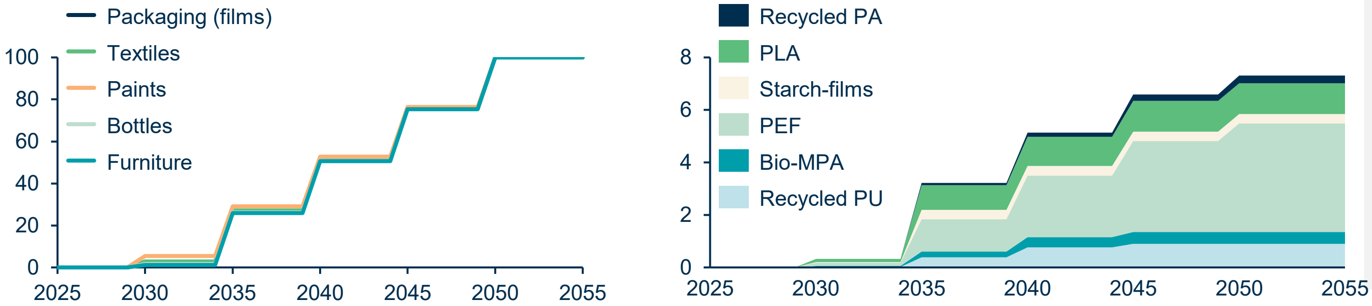
Implementing bio-plastic targets with PPWR can be an easy route for implementation, but to seize full reduction potential, more stringent targets must be considered.

What are the effects of phasing in targets?

Potential bio-plastic phase-in in line with PPWR and resulting created demand.

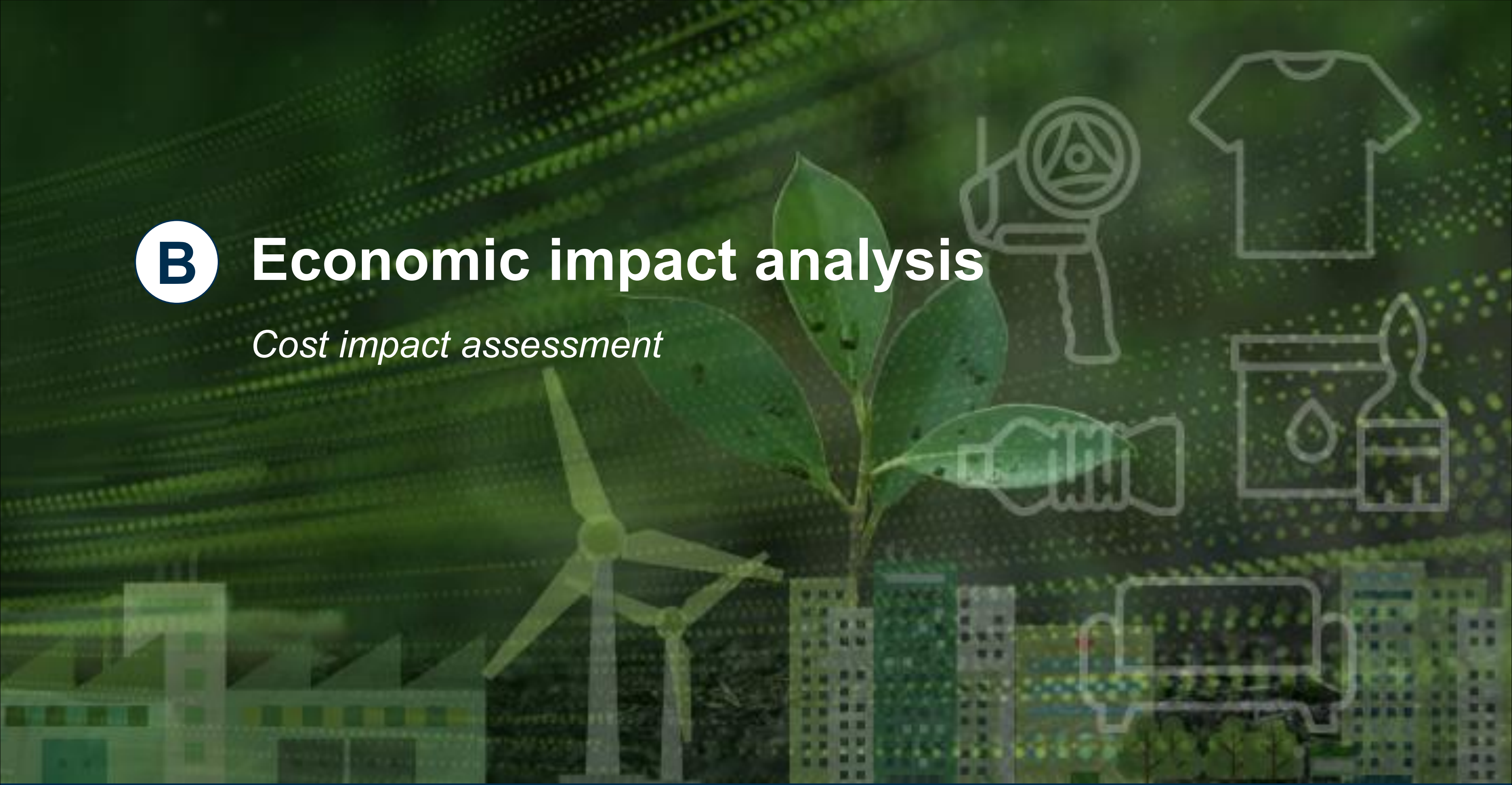


Proposed phase in of targets and resulting demand growth



Comments

- It is possible to include bio-polymers in the PPWR, where targets for 2030 and 2040 are already set. In 2030 a target of 35% alternative polymers is set for the (non-food) packaging excluding PET and a 30% target for PET bottles. By 2040 the target for both groups is raised to 65%.
- The proposed phase in starts at the minimal calculated target for the product groups and builds up to 100% by 2050 to meet net zero targets.
- Phasing in the target gives the market time to respond to the changes, as well as it gives a clear signal for the upcoming demand for nascent markets.
- The exact level of a target is less important than the clarity of providing a target. Providing clarity signals the market to spring into action.
- The volumes are based on current polymer demand and do not factor in the changing demand as a result of new technologies or consumption patterns.



B Economic impact analysis

Cost impact assessment

The impact of an alternative plastic target is assessed on a product level. The cost-impact for the end user is estimated, as well as the impact on the emerging market.

Cost impact assessment

Product groups	Products selected per sustainable polymer alternative	
Plastic films, sheets, plates, foil, strip (packaging)	**PLA** as a substitute for PP **PP-tape** 	**Starch** as a substitute for PE-LD **Textile poly mailer** 
Textiles and apparel	**Recycled PA** as a substitute for PA **Sport shirts** 	**PEF** as a substitute for PET **Fleeces** 
Paints and varnishes	**Bio-MPA** as a substitute for alkyds (e.g. phthalic anhydride) **Wall paint** 	**PLA** as a substitute for vinyl (e.g. ethylene vinyl acetate) **Paint primer** 
Plastic bottles and containers	**PEF** as a substitute for PET **PET-fles** 	
Furniture	**Recycled PU** (chemical) as a substitute for PU: **2-person sofa** 	

🟦 Recycled

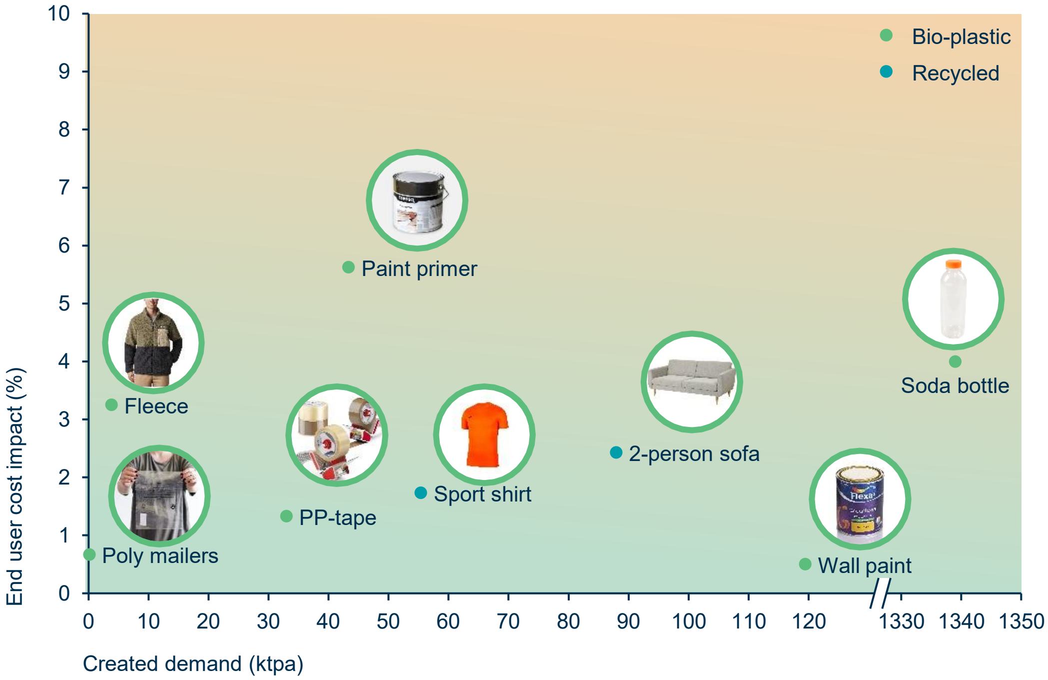
🟩 Bio-based

Approach

1. Typical products are selected for the different product groups.
2. The required volume of alternative polymer is assessed for each single product unit.
3. The price difference between the conventional and alternative polymers leads to a change in production costs.
4. The change in production costs is compared with the typical costs of the application of the product for an end user. This results in the product cost impact.

The impact of a sustainable polymer target is manageable for end users. In the worst case, at full substitution and at current price levels, the highest cost increase is 5.7%.

Worst case cost impact for end users



Insights

- A sustainable polymer target is **most effective on high volume / fast moving products**. Cost impact is low for products that **currently contribute little to total end-use costs,** such as poly mailers or tape.
- The calculated cost impact is a worst case. The impact is calculated at current price levels and at a 100% sustainable polymer target. Even in the worst case, the cost impact is manageable, as plastic containing products are only a fraction of total household spending.
- The current price difference between polymers is used to calculate the cost impact. This difference is likely to drop, with production of alternatives scaling up and reaching economies of scale and improving production processes with lessons learned. At the same time, the costs of fossil polymers are likely to rise with carbon pricing becoming more stringent.
- Premium stacking effects are not considered in this analysis. When implementing the responsibility for the target in a correct manner, such as a book and claim system, this effect can be negated.

See the cost impact assessment sources and assumptions in the appendix.

Substitution in soda bottles at scale can generate high demand for alternative polymers with minimal impact on shelf prices for the consumer.

Results: Cost impact on product a soda bottle

Product Card

Product definition: 1L clear PET soda bottle

EU Demand for product: 76.5 million units/year

Total polymer mass: 22g per unit

Fossil polymer type: PET

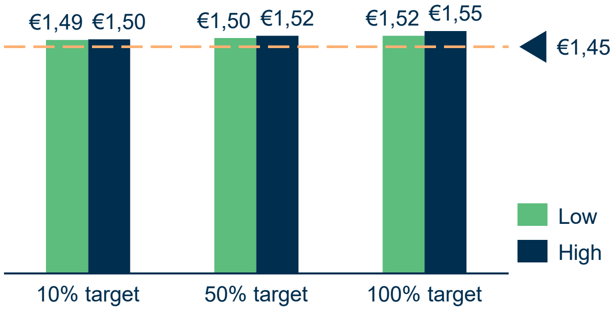
Alternative polymer type: PEF

Fossil polymer cost: € 690 – €1.640/t

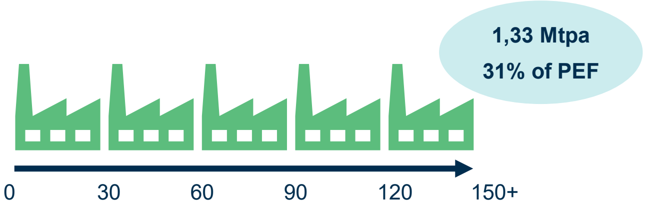
Alternative polymer cost: €3.330 – €3.870/t

Impact of a norm on a soda bottle

Green premium on a cola bottle



Contribution towards viable market



Insights

- A soda bottle contains very little polymer, yet Europeans buy so many of them that substitution quickly adds up, **22 grams** per bottle becomes more than **1.3 million tons** of alternative polymer each year.
- A 1-litre Coca Cola bottle contains 22 grams of fossil PET today, equating to an increase in production cost by **€0,06 per bottle** under the high-case scenario.
- At shelf level, that would turn a typical **€1,49** bottle into roughly **€1,55,** a change smaller than routine weekly price swings caused by promotions.
- This single fast moving consumer goods (FMCG) item alone could support many PEF plants. Targeting FMCG items is effective in creating demand.

For sources and assumptions, see the appendix

Large volumes and high polymer content make wall paint a strong driver for alternative polymer demand, while potentially even being more cost-effective.

Results: Cost impact on wall paint

Product Card

Product definition: 1L can of white paint

EU Demand for product: 442 million units/year

Total polymer mass: 300g per unit

Fossil polymer type: Alkyds

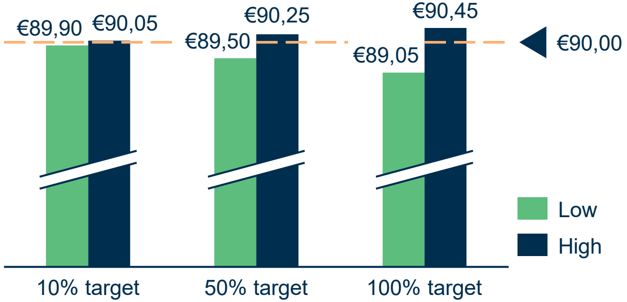
Alternative polymer type: Bio-MPA

Fossil polymer cost: €905 – 781t

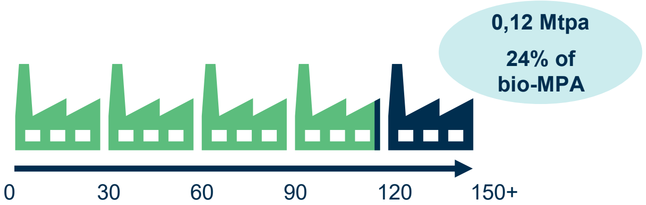
Alternative polymer cost: €2.785 – €1.745t

Impact of a norm on a wall paint

Green premium on painting 50 m²



Contribution towards viable market



Insights

- A 1L can carries **300 grams** of polymer, whilst EU demand is significant at over **440 million cans per year**.
- The **€0,09 per can increase** means painting 50 m² of wall in an apartment (requiring 5L of paint) would cost **€0,45 more** under a 100% norm, essentially negligible relative to labor and renovation costs.
- Yet collectively, this category generates **119 ktpa** of alternative polymer demand, a substantial contribution to market creation.
- Based on market research, bio-MPA was found to be more cost-effective than acrylics in some cases. It also offers superior durability, requiring less frequent repainting, which further strengthens its position as a cost-effective alternative.

For sources and assumptions, see the appendix

Sofas offer policymakers a high impact category where substitution offers significant material shifts without affecting consumer affordability.

Results: Cost impact on a 2-person sofa

Product Card

Product definition: Grey Ikea 2-person sofa

EU Demand for product: 7.27 million units/year

Total polymer mass: 11000g per unit

Fossil polymer type: PU

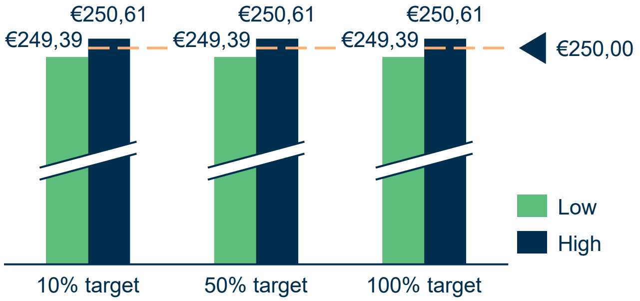
Alternative polymer type: Recycled PU

Fossil polymer cost: €1.900 – €1.600/t

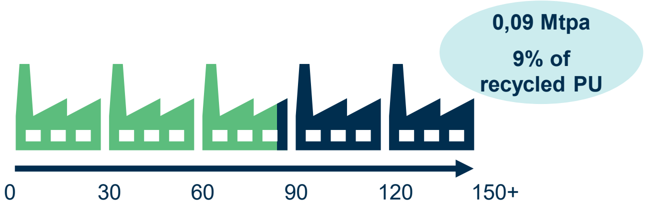
Alternative polymer cost: €2.100 – €1.400/t

Impact of a norm on a fleece

Green premium on a 2-person sofa



Contribution towards viable market



Insights

- A single 2-person sofa contains approximately **11 kg of fossil polymer**, giving the category a high polymer footprint and strong case for substitution strategies.
- With **7.2 million units sold per year**, this category generates nearly **88 ktpa of alternative polymer demand.**
- While the **€6,05 per unit impact** is the highest of all assessed products, it's almost negligible relative to retail prices (€250 - 400+), making polymer substitution extremely price insensitive for consumers. Especially considering how infrequent consumers buy a first-hand sofa.

For sources and assumptions, see the appendix

The combination of a high polymer content, high market demand and low cost impact, makes sport shirt an impactful category for material substitution.

Results: Cost impact on a sports shirt

Product Card

Product definition: A generic sports shirt

EU Demand for product: 400 million units/year

Total polymer mass: 126g per unit

Fossil polymer type: PA

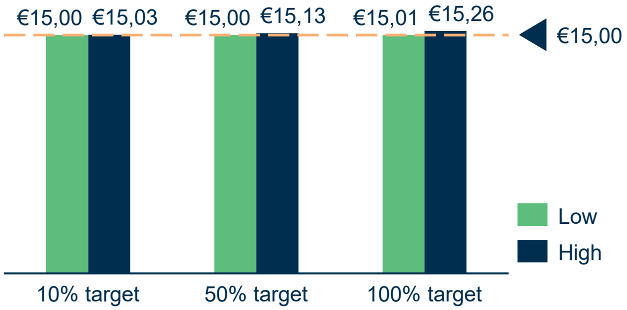
Alternative polymer type: Recycled PA

Fossil polymer cost: €1.640 – €690/t

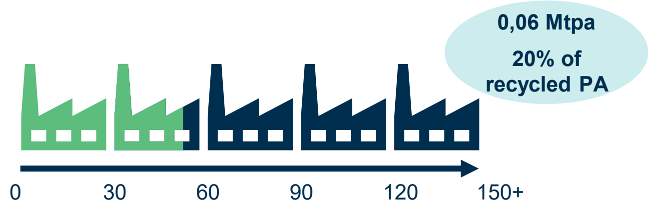
Alternative polymer cost: €4.090 – €3.330/t

Impact of a norm on a sports shirt

Green premium on a typical sports shirt



Contribution towards viable market



Insights

- Sports shirts have a high polymer content, with **126 grams of polymer,** per typical 140-gram item.
- With an EU demand of **400 million units annually**, the category generates a substantial **55 ktpa** of alternative polymer demand.
- A **€0,26 per unit** increase barely registers next to typical retail prices (€10 - 25), giving brands ample pricing room for bio-based upgrades.
- The combination of high polymer content and a high market demand, make this an effective product for carbon reduction.

For sources and assumptions, see the appendix

A target on paint primer can support an emerging market, while financially barely impacting the end user.

Results: Cost impact on paint primer

Product Card

Product definition: 1L white paint primer

EU Demand for product: 96 million units/year

Total polymer mass: 450g per unit

Fossil polymer type: EVA

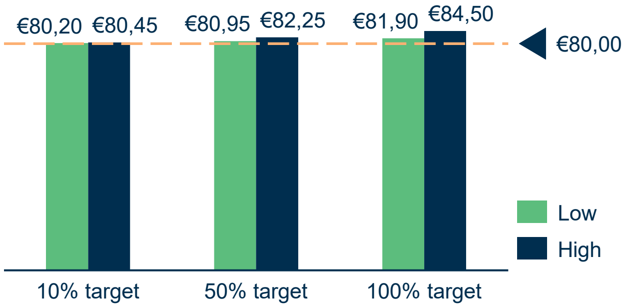
Alternative polymer type: PLA

Fossil polymer cost: €905 – 781/t

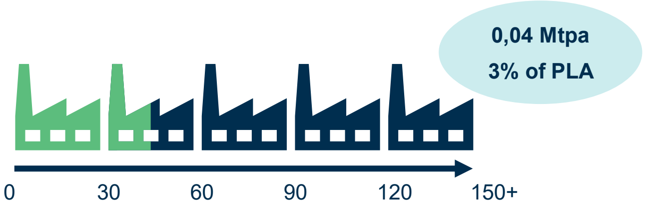
Alternative polymer cost: €2.785 – €1.745/t

Impact of a norm on *paint primer*

Green premium



Contribution towards viable market



Insights

- Primer contains even more polymer per unit than wall paint, **450 grams of alternative polymer per liter**, but demand volume is lower.
- The **€0,90 per unit increase** is still minor in the context of renovation budgets. For a 50 m² surface, requiring one coat of primer (5L), the total added cost would be **€4,51**.
- Total demand can be more than **43 ktpa**, making primer a helpful but not standalone driver of alternative-polymer deployment.

For sources and assumptions, see the appendix

The low contribution of PP-tape costs toward end-use application costs results in a barely noticeable impact of a sustainable polymer target for end users.

Results: Cost impact on product PP-tape

Product Card

Product definition: PP hot melt tape transparent

EU Demand for product: 210 million units/year

Total polymer mass: 143g per unit

Fossil polymer type: PP

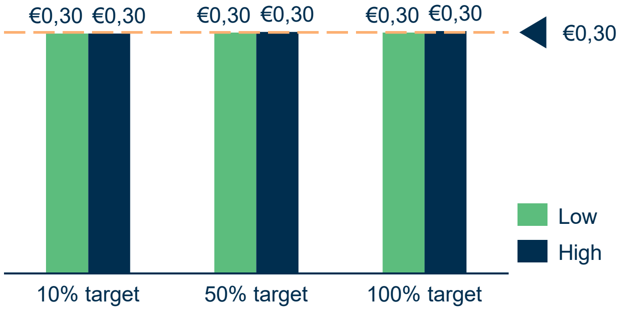
Alternative polymer type: PLA

Fossil polymer cost: €1.170 – € 995/t

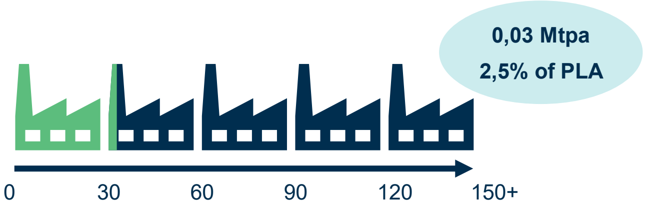
Alternative polymer cost: €2.785 – €1.745/t

Impact of a norm on pp-tape

Green premium on 30x20x15 cm package



Contribution towards viable market



Insights

- A roll of PP tape contains **over 140 grams per roll**, so each substitution has a noticeable material footprint.
- With 210 million rolls sold annually, over **33 kton of alternative-polymer demand is created annually** at a 100% norm.
- Based on the assumption that only around 1.5%[1)] of a roll is used to seal a medium-sized box, the **€0,23 cost impact per roll** translates to just **€0,001 to €0,004 per use.**

For sources and assumptions, see the appendix

1) A typical roll contains 66 m, and roughly 1 m is used on a 30x20x25 cm package.

A sustainable polymer target only has a small impact on the price of fleeces, but it does not contribute much to total demand due to the small market size.

Results: Cost impact on a fleece

Product Card

Product definition: Men's medium ¼ zip fleece

EU Demand for product: 20 million units/year

Total polymer mass: 212g per unit

Fossil polymer type: PET

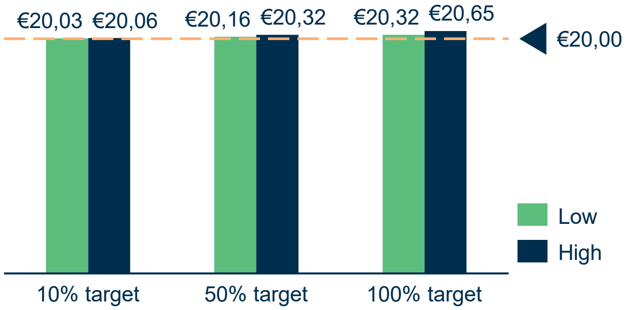
Alternative polymer type: PEF

Fossil polymer cost: €2.098 – €1.398/t

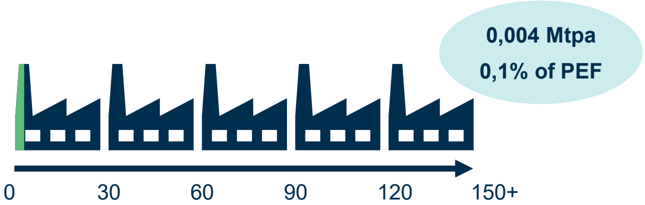
Alternative polymer cost: €3.250 – €2.170/t

Impact of a norm on a fleece

Green premium on a typical fleece



Contribution towards viable market



Insights

- A fleece is one of the more polymer dense consumer goods in the product portfolio, with more than **200 grams per unit**.
- Yet market volume is small, so total demand reaches just under **4 ktpa.**
- The **€0,65 increase** per garment remains small relative to typical retail prices (€20 - 40), making material substitution commercially feasible.
- Fleeces show how high-mass, low-volume apparel items contribute meaningfully per unit but **cannot drive sector-wide demand creation** without being grouped with other textile products.

Poly mailers add negligible cost when substituted, but their extremely low material mass limits their contribution to overall polymer demand.

Results: Cost impact on poly mailer

Product Card

Product definition: Poly mailer used for shipping

EU Demand for product: 9 million units/year

Total polymer mass: 9,9g per unit

Fossil polymer type: PE-LD

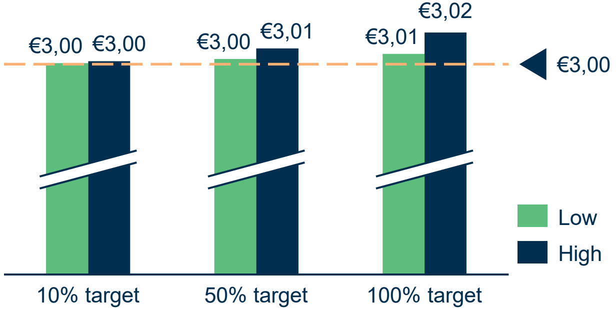
Alternative polymer type: Starch (film)

Fossil polymer cost €1.300 – €1.110/t

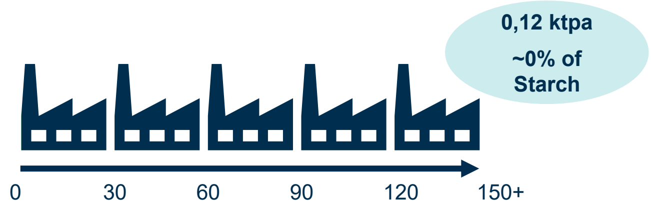
Alternative polymer cost: €2.760 – €1.840/t

Impact of a norm on poly mailer

Green premium on shipping costs



Contribution towards market creation

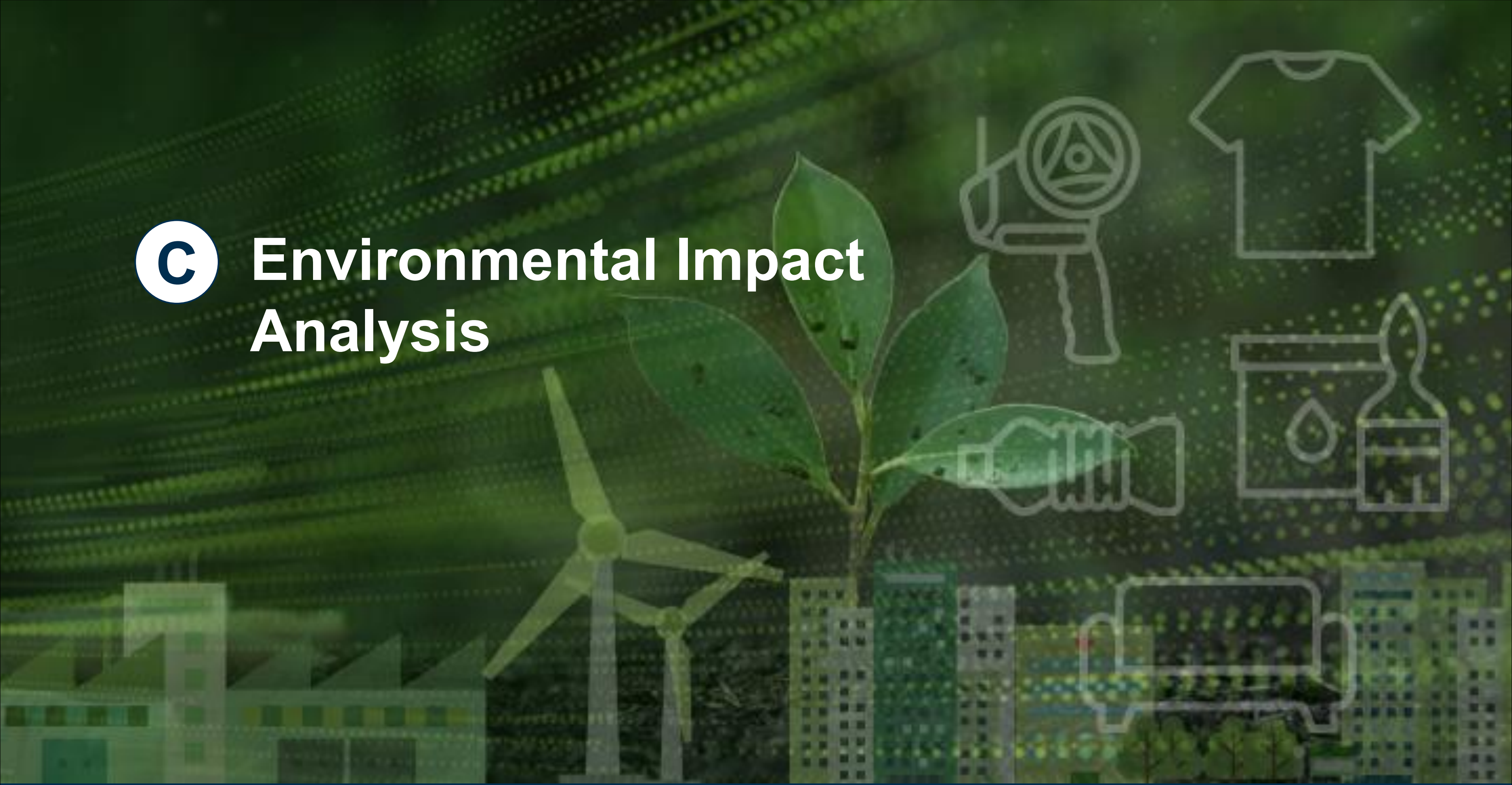


Insights

- Poly mailers are extremely light, barely 10 grams, which means even at **9 million units per year**, total alternative polymer demand remains minimal.
- The **€0,02 per-unit impact** is very low compared to fulfilment, picking, and shipping costs. For the end user, their costs are **negligible** compared to typical **€3,00 apparel shipping costs.**
- Even when total EU poly mailer demand is substituted, the resulting demand is just 0,12 kilotons per year.
- Poly mailers are technically easy to substitute, but the low weight per product leads to a small contribution towards viable market creation, even at a 100% norm.

For sources and assumptions, see the appendix

C Environmental Impact Analysis



The sustainable alternatives considered in this study all show a significant environmental impact advantage over the use of conventional fossil polymers

Overview of results of environmental impact analysis within cradle-to-gate scope

Industry	**Product group**	**Fossil polymer**	**Sustainable alternative**	**Environmental impact score of substitution per category and total**					
				Climate change (21,06%)	Resource use (8,32%)	Particulate matter (8,32%)	Land use (7,94%)	Ecotoxicity (1,92%)	**Total** [1]
Packaging	Plastic films, sheets and foils	PE-LD	Starch	🟢	🟢	🔴	🔴	🔴	🟢
		PP	PLA	🟢	🟢	🔴	🔴	🔴	🟢
	Plastic bottles and containers	PET	PEF	🟢	🟢	🔴	🔴	🔴	🟢
Textiles	Textiles and apparel	PA	Recycled PA	🟢	🟢	🟢	🔴	🟠	🟢
Chemicals	Paints/varnishes based on polymers	Phthalic anhydride[2]	Bio-MPA[3]	🟢	🟢	🔴	🔴	🔴	🟢
		EVA[4]	PLA	🟢	🟢	🔴	🔴	🔴	🟢
Houseware, leisure & sports	Furniture	PU foam	Recycled PU foam	🟢	🟢	🟢	🟢	🟢	🟢

Legend
🟢 Significant advantage for sustainable alternative
🟠 No significant difference
🔴 Significant disadvantage

---

[1] The total environmental impact score of substitution is determined as a sum of the five impacts per categories, considering their weighing factors (%). Due to limited data availability, the environmental impact analysis is conducted quantitatively wherever possible and qualitatively where data are lacking.

[2] Phthalic anhydride is an alkyd; [3] Bio-based maleic phthalic anhydride; [4] Ethylene vinyl acetate is a vinyl.

In general, circular and bio-based polymers have lower environmental impacts than virgin fossil polymers; substitution should be stimulated to accelerate their learning curves

Trends and comparison of virgin fossil polymers and sustainable alternatives

Fossil polymers

Virgin (fossil)

Virgin fossil polymers are produced from **fossil hydrocarbon feedstocks** and are associated with relatively high carbon footprints across the life cycle. Their climate impacts are primarily driven by **fossil feedstock** use and **fossil energy consumption** during production, typically via refinery routes and steam cracking followed by polymerization.

Steam cracking explicitly converts fossil hydrocarbons (e.g. ethane, LPG, naphtha, gas oil) into polymer precursors, embedding fossil carbon in the material. At end-of-life, incineration releases this fossil carbon as CO_2, directly contributing to climate change, in contrast to bio-based polymers, whose emissions are biogenic.

These production routes are **highly mature** and have been optimized over decades, meaning that **only limited efficiency** gains are possible. Further reductions in the climate impact of fossil polymer production would require investments in major technological shifts, such as electrified or hydrogen-based steam cracking, rather than improvements within the current way of production.

Sustainable alternatives

Recycled (fossil)

Recycled polymers are increasingly used to reduce reliance on virgin fossil resources and support **circular economy objectives**. Their environmental performance depends strongly on waste collection, sorting efficiency, and material quality.

Mechanical recycling is the main route and typically has lower climate impacts than virgin production, but material degradation limits recycling cycles and can affect the final recycled products quality.

Chemical recycling is an alternative option for complex waste streams, though it involves higher energy use and material losses.

Policy targets to reduce incineration and **increase recycled content** are key drivers, making **design-for-reuse and recycling** and improved waste management increasingly important to achieving environmental benefits.

Bio-based

Bio-based polymers replace fossil feedstocks with **biomass-derived resources** and therefore reduce fossil resource depletion and climate impacts. However, their environmental performance is strongly influenced by land use, water consumption, and agricultural inputs such as fertilizers, and varies significantly by feedstock, region, and farming practices.

Sustainable agricultural practices, certification schemes (e.g. ISCC), and cooperation with local producers are therefore critical to ensure responsible sourcing and to minimize land-use and biodiversity impacts. The use of residues and waste streams, as well as feedstock diversification, can substantially lower environmental burdens.

From a **life-cycle perspective**, bio-based polymers can offer an advantage at end-of-life: when incinerated, they **release biogenic rather than fossil CO_2,** resulting in lower net climate impacts compared to fossil-based polymers, including recycled fossil plastics.

The environmental impacts of the fossil and sustainable polymers are assessed using a cradle-to-gate life cycle approach: from raw material sourcing to granulate production

Scope of the life cycle assessment in this research

Cradle-to-gate: in scope

The environmental impacts of fossil and sustainable polymers are assessed according to *Environmental Footprint 3.1 (adapted) V1.03 / EF 3.1 normalization and weighting*, using a **cradle-to-gate life cycle assessment approach**[1). The assessment includes all processes **from raw material extraction** and processing, the production of monomers and polymers, **up to granulate production** at the factory gate.

These upstream stages are where the **largest environmental differences** between fossil and sustainable feedstocks typically occur and where fossil polymers are substituted by sustainable alternatives.

Gate-to-grave: out-of-scope

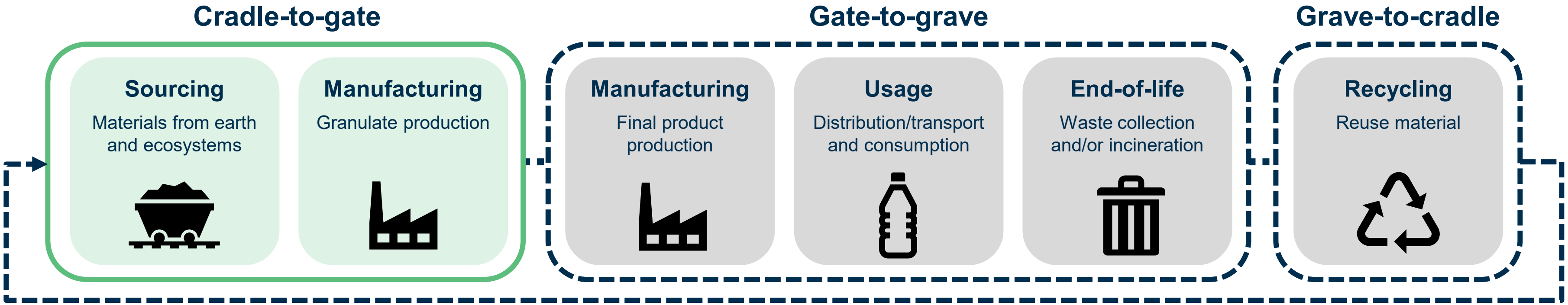
Downstream life-cycle stages, including transport, the use phase and end-of-life, are excluded in this analysis. These stages are assumed to be largely independent of the polymer feedstock and primarily driven by application-specific factors and waste-management systems rather than by the origin of the material.

Excluding these stages avoids introducing differences that cannot be attributed to the polymer material itself and ensures a consistent comparison focused on material substitution.

Grave-to-cradle: out-of-scope

Recycling and other **circular pathways** are excluded in this analysis. While relevant for broader circularity assessments, these processes are considered to belong to a ‘subsequent life cycle’ of the material.

For recycled materials, a **cut-off approach** is used which assumes that the environmental impact of recycled feedstock belongs to a previous life cycle.



Cradle-to-gate

Sourcing
Materials from earth and ecosystems

Manufacturing
Granulate production

Gate-to-grave

Manufacturing
Final product production

Usage
Distribution/transport and consumption

End-of-life
Waste collection and/or incineration

Grave-to-cradle

Recycling
Reuse material

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1) In line with EU standards.
2) Source: Eco-profiles set • Plastics Europe, Life Cycle Assessment & the EF methods - Green Forum

This study uses five impact categories to assess the environmental impact of sustainable polymers

The five impact categories, their units and single score weight

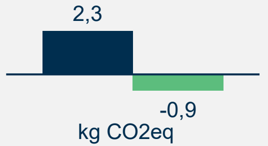
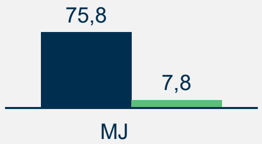
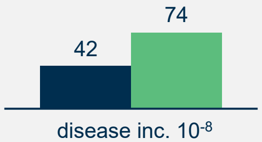
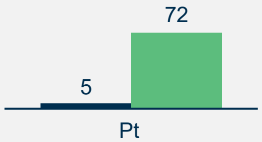
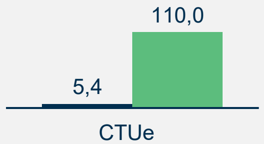
Impact category[1]	Explanation	Unit	Single score weight[2] %
Climate change (incl. biogenic CO_2 uptake)	The **climate change** impact category, also known as Global Warming Potential over 100 years (GWP100), reflects the contribution of greenhouse gas (GHG) emissions and removals to changes in global average temperature. Fossil-based polymers typically show higher climate impacts due to emissions from fossil fuel extraction, processing and polymer production. For bio-based polymers, biogenic carbon uptake during biomass growth is accounted for using the +1/–1 approach[3]. All GHG emissions and removals are expressed in kilograms of CO_2-equivalent (kg CO_2-eq), meaning several greenhouse gases (methane, nitrous oxide, etc.) are compared to the warming effect of 1 kg of fossil CO_2.	kg CO2 eq	21,06%
Resource use (fossil)	**Resource use, fossil** reflects the depletion of non-renewable resources such as coal, oil, and natural gas. Using fossil fuels today reduces what is available for future generations. This category includes both direct fossil energy use (e.g., fuel combustion) and indirect use (e.g., fossil feedstock for chemicals). Bio-based or recycled plastics help reduce the demand for virgin fossil resources and support circularity. The amount of material contributing to resource use, fossils, are converted into MJ.	MJ	8,32%
Particulate matter	**Particulate matter** assesses how emissions of Particulate Matter (PM) and precursors such as NOx and SO_2 affect human health. Smaller particles are generally more harmful because they reach deeper parts of the lungs. The indicator describes the potential change in mortality linked to PM emissions and is reported as disease incidence per kilogram of $PM_{2.5}$ released.	Disease incidence	8,32%
Land use	**Land use** reflects how land is occupied or transformed for activities such as agriculture (for food and non-food crops), infrastructure, or mining, leading to impacts like biodiversity loss, reduced soil organic matter, and erosion. It is measured as a composite indicator (expressed in points) capturing effects on biotic production, erosion resistance, groundwater regeneration, and mechanical filtration.	Pt	7,94%
Ecotoxicity	**Ecotoxicity** describes the potential toxic impacts on an ecosystem, which may damage individual species as well as the functioning of the ecosystem. Some substances tend to accumulate in living organisms, such as hazardous chemicals and wastewater release. The unit of measurement is Comparative Toxic Unit for ecosystems (CTUe).	CTUe	1,92%

1) These are the four impact categories with the largest single score weight supplemented with ecotoxicity in consultation with Ministry of Infrastructure and Water. Water use is not considered due to high uncertainty and variability in water flows data.
2) This single score percentage is defined by the EU in EF 3.1 and indicates the relative importance of each impact category. The 16 categories together total 100%, of which the selected categories account for 48.2%.
3) The +1/–1 approach is applied to reflect biogenic carbon uptake during biomass growth and does not imply that carbon is permanently stored.
Source: Environmental Footprint 3.1 method (European Union, 2023), Life Cycle Assessment & the EF methods - Green Forum

Using starch (film) as a substitute for PE-LD results in a significantly lower environmental impact for climate change and resource use

Quantitative comparison of PE-LD and starch (film) per impact category

Product Category: Packaging – films

Impact category	**Climate change[1]**	**Resource use (fossil)**	**Particulate matter**	**Land use**	**Ecotoxicity**
🟦 PE-LD 🟩 Starch					
Qualitative analysis	When biogenic carbon uptake is included, **starch** shows a **net negative climate change impact**. This is because carbon dioxide absorbed from the atmosphere during crop growth exceeds the fossil greenhouse gas emissions associated with agricultural operations and starch processing. In contrast, **PE-LD** is fully fossil-based and shows a climate change impact driven by fossil feedstock extraction, steam cracking of ethylene, and energy-intensive polymerization.	PE-LD shows **high fossil resource use**, driven by fossil feedstocks, energy-intensive steam cracking, and polymerization at very high pressures. Starch production relies on **renewable biomass feedstocks**, resulting in substantially lower fossil resource depletion, although fossil energy is still used in farming operations, fertilizer production, and processing.	The particulate matter impact of starch-based materials is driven by fertilizer-related emissions (notably NH_3 and NO_x) and combustion emissions from field operations (e.g. often diesel use), associated with crop cultivation and upstream agricultural inputs.	As land occupation is inherent to biomass production, starch-based materials typically show higher land use impacts than fossil-based PE-LD.	Starch-based materials show higher freshwater ecotoxicity risk than PE-LD due to pesticide application and nutrient emissions during agricultural cultivation.
Substitution score	🟢	🟢	🔴	🔴	🔴

Legend: ≤ –20%: significant advantage for sustainable alternative | 20% < Δ < +20%: no significant difference | ≥ +20%: significant disadvantage

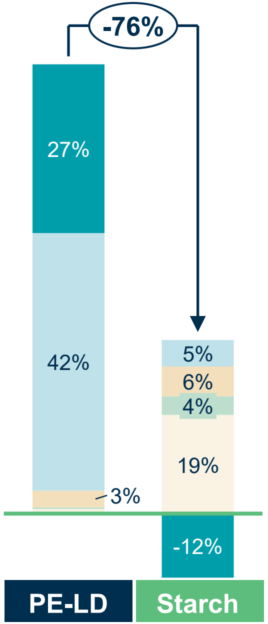
1) Data used from Starch Europe (native starch and lightly modified starch). Biogenic carbon uptake is calculated based on the carbon content of native starch. Following standard LCA practice (EN 15804), biogenic carbon retained in the feedstock was converted to CO_2 equivalent using the 44/12 stoichiometric factor (reflecting CO_2 molecular weight), resulting in an uptake of approximately −1.6 kg CO_2-eq per kg dry starch.

Starch (film) has a significantly lower environmental footprint compared to PE-LD

Product Category: Packaging – films

Quantitative comparison of PE-LD and starch (film) single score and additional qualitative assessment

Single score [% points]



Other significant advantages not included in the single score ●

Starch-based materials show a **clear advantage in water use** compared to PE-LD. Ethylene production via steam cracking is extremely heat-intensive and requires large amounts of cooling water to manage furnace and reactor temperatures.

Additionally, PE-LD polymerization occurs at very high pressures (up to ~3000 bar), requiring further cooling and compression systems. These aspects are not fully reflected in aggregated single-score indicators.

Other significant disadvantages not included in the single score ●

For performance-based functional units, starch-based materials may require greater material thickness or blending to compensate for lower mechanical strength and **moisture resistance**, potentially increasing impacts per functional unit. This effect is formulation- and application-dependent and is not reflected in mass-based LCAs.

The exact thickness depends on the application. If e.g. double the material is needed for starch film, the environmental impact becomes twice as high.

Uncertainties ●

The LCA is based on environmental profiles of starch industry products in the EU-27 for the reference year 2019. However, some factors are country and regional specific. Specifically, for agricultural processes (land use, particulate matter, and ecotoxicity), as results are sensitive to crop yields, fertilizer and pesticide application rates, fuel use in field operations, and regional farming practices.

Potential improvements ●

Improved fertilizer management, reduced pesticide use, and higher starch recovery efficiencies could significantly reduce impacts in particulate matter and ecotoxicity categories.

In this impact analysis starch made from maize is used, however starch can be made from wheat, sugarcane and algae. These alternatives could have a lower environmental impact.

- ■ Climate Change
- ■ Particulate Matter
- ■ Ecotoxicity
- ■ Resource use
- ■ Land use

Total environmental impact score of substitution[1]: ●

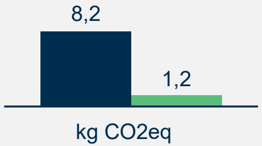
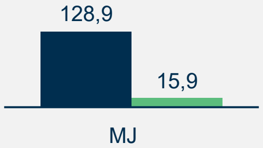
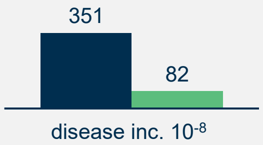
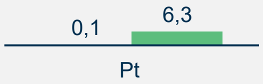
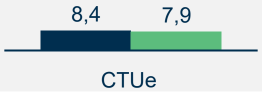
Legend: ≤ –20%: significant advantage for sustainable alternative | 20% < Δ < +20%: no significant difference | ≥ +20%: significant disadvantage

1) The total environmental impact score of substitution takes into account the weighing factors of the five categories.

Using recycled PA (approximated using rPET data) as a substitute for virgin PA results in a significantly lower environmental impact

Indicative quantitative comparison of polyamide and recycled PET (rPET)[1)]

Product Category: Packaging – films

Impact category	**Climate change**	**Resource use (fossil)**	**Particulate matter**	**Land use**	**Ecotoxicity**
Quantitative indication ■ PA 🟩 rPET					
Qualitative analysis virgin and recycled PA	Virgin PA has a high climate change impact due to fossil feedstock extraction, monomer production, and energy-intensive polymerization. **Mechanical** recycling typically has the lowest impact by avoiding fossil feedstock and requiring low processing energy. **Chemical** recycling has a high energy demand due to depolymerization and purification, but usually remains significantly lower than virgin PA.	Virgin PA relies entirely on fossil resources for both feedstock and energy. **Mechanical** recycling significantly reduces fossil resource use as no new feedstock is required. But it requires energy for sorting, shredding, melting, and pelletizing. **Chemical** recycling also avoids primary fossil feedstock but requires more energy and auxiliary inputs than mechanical routes.	Virgin PA has higher particulate matter impacts linked to upstream energy and chemical production. **Mechanical** recycling generally shows the lowest impact. **Chemical** recycling can result in higher PM emissions due to thermal processes, but typically remains below virgin PA	The land use of PA is extremely low, the LCA data of rPET shows higher environmental impact, but this is still significantly lower compared to bio-based options.	There is no significant difference in ecotoxicity impact between recycled and virgin polyamide. For virgin PA, ecotoxicity impact is driven by petrochemical processes, catalysts, and wastewater emissions. **Mechanical** recycling is generally lower or comparable, driven by washing and wastewater treatment. **Chemical** recycling can introduce solvent- and catalyst-related risks but is usually still lower than virgin PA when well controlled.
Substitution score	🟢	🟢	🟢	🔴	🟠

Legend: 🟢 ≤ –20%: significant advantage for sustainable alternative 🟠 20% < Δ < +20%: no significant difference 🔴 ≥ +20%: significant disadvantage

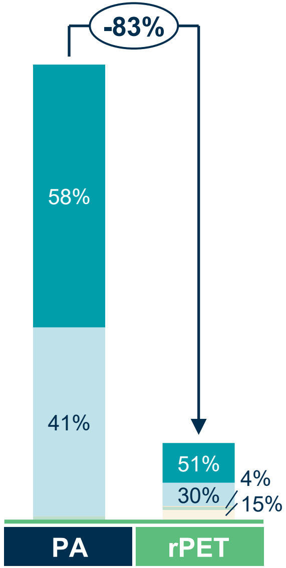
1) To give a quantitative indication of the environmental impact advantage of recycling, the climate impact of PA is compared to the climate impact of mechanical recycled PET due to no data availability of recycled PA.

Recycled PA has a significantly lower environmental footprint than virgin PA; however, specific rPA LCA data is needed to confirm this

Indicative quantitative comparison of PA and recycled PET single score and additional qualitative assessment[1)]

Product Category: Packaging – films

Single score [% points]



Significant advantages not included in the single score ●

No additional advantages have been clearly identified beyond those already captured in the analysis.

Uncertainties ●

Environmental impacts vary by **recycling route, technology choice, and regional energy mix**. Due to limited availability of recycled PA-specific LCA data, **mechanically recycled rPET is used as a proxy**, as the recycling processes are comparable. This provides an indication of the climate impact advantage of mechanically recycled PA, but there remains uncertainty in the exact impact.

Significant disadvantages not included in the single score ●

Mechanical recycling can generate **microplastics** during shredding, grinding, and washing processes; these impacts are not fully captured in EF 3.1. Mechanical recycling also requires washing, increasing **water use and wastewater generation**. In addition, **material degradation** during mechanical recycling can limit the number of recycling cycles and affect material quality.

Chemical recycling typically requires less washing water but may introduce **solvent-containing waste streams** that require careful treatment. Additionally, chemical recycling will lead to material loss.

Potential improvements in production ●

Environmental performance can be further improved through **higher collection rates**, improved sorting, and increased availability of **mono-material or recyclable packaging designs**. PA is often used in **multilayer packaging**, which is difficult to recycle; emerging technologies and design-for-recycling measures could significantly improve recycling yields and impact performance over time.

■ Climate Change ■ Particulate Matter ■ Ecotoxicity
■ Resource use ■ Land use

Total environmental impact score of substitution: ●

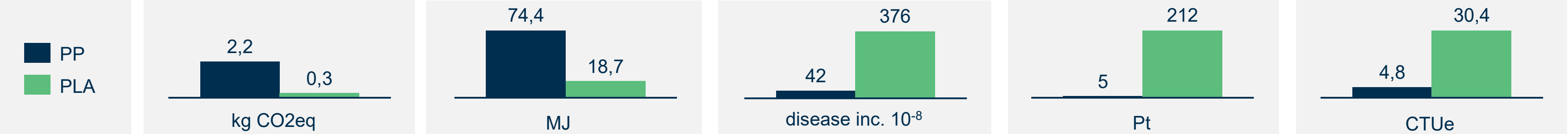
Legend: ≤ –20%: significant advantage for sustainable alternative | 20% < Δ < +20%: no significant difference | ≥ +20%: significant disadvantage

1) To give a quantitative indication of the environmental impact advantage of recycling, the climate impact of PA is compared to the climate impact of mechanical recycled PET due to no data availability of recycled PA.

Using PLA as a substitute for PP results in a significantly lower environmental impact for climate change and resource use

Quantitative comparison of PP and PLA per impact category

Product Category: Packaging – films



Impact category	**Climate change (incl. biogenic carbon uptake)**	**Resource use (fossil)**	**Particulate matter**	**Land use**	**Ecotoxicity**
PP / PLA	PP 2,2 / PLA 0,3 kg CO2eq	PP 74,4 / PLA 18,7 MJ	PP 42 / PLA 376 disease inc. 10^{-8}	PP 5 / PLA 212 Pt	PP 4,8 / PLA 30,4 CTUe
Qualitative analysis	Including biogenic carbon uptake, PLA shows a clear climate-change advantage over PP. For **PP**, climate impact is mainly driven by fossil feedstock and fossil energy used to produce polypropylene. For **PLA**, the main contributors sit upstream in the bio-based value chain: climate impact is primarily driven by the production of process chemicals (43%, mainly lime), followed by sugar production (23%) and steam (19%).	PLA has a significantly lower fossil resource use than PP. **PP** relies entirely on fossil feedstock and fossil energy for cracking and polymerization. **PLA** has much lower fossil resource use, because the carbon in the polymer is biogenic (from sugars). The remaining fossil demand is mainly linked to steam and electricity use and upstream chemical and agricultural inputs, such as fertilizer production and energy use during fermentation and polymerization.	The particulate matter impact of PLA is driven by fertilizer-related emissions and combustion emissions from field operations, mainly associated with sugar production (66%) and chemical production (28%).	The land use impact of PLA is dominated by sugar production (93%), making this impact highly sensitive to crop yields, allocation choices, sugar recovery efficiency, and conversion efficiency.	PLA shows higher ecotoxicity risk than PP due to fertilizer and pesticide use and nutrient emissions during feedstock cultivation, affecting soil and water compartments.
Substitution score	🟢	🟢	🔴	🔴	🔴

Legend: 🟩 ≤ –20%: significant advantage for sustainable alternative 🟨 20% < Δ < +20%: no significant difference 🟥 ≥ +20%: significant disadvantage

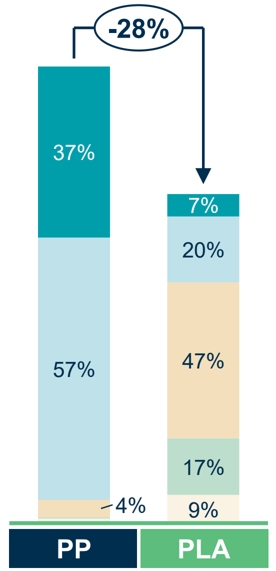
Source: Total Energies - Corbion

PLA has a significantly lower environmental footprint compared to PP; with room left for further improvements in PLA production

Product Category: Packaging – films

Quantitative comparison of PP and PLA single score and additional qualitative assessment

Single score [% points]



Significant advantages not included in single score ●

Ozone depletion and minerals/metals resource use can be favorable for PLA depending on the energy/chemicals profile.

PLA has an additional end-of-life accounting benefit when biogenic carbon is considered: CO_2 released on incineration is renewable in origin (biogenic), unlike PP's fossil carbon which increases net GWP.

PLA has a defined route to **chemical recycling back to lactic acid**, enabling recycled-content grades with strong climate performance when biogenic carbon is included.

Uncertainties ●

Impact category uncertainty is typically higher for categories tied to agricultural emissions and modelling choices (including particulate matter, land use and ecotoxicity), and results should be interpreted with attention to dataset representativeness and regional validity.

PLA is made of starch. The EcoInvent impact calculations of starch are based on older cultivation data (Germany, 2003), meaning improvements in farming practices are not fully reflected, making the estimate conservative.

Significant disadvantages not included in single score ●

PLA has a water use disadvantage. Water use contributions come mainly from **lactic acid production (43%)** and **sugar production (39%)**. However, it should be noted that water use is location-specific and therefore uncertain across production geographies

PLA's climate impact is heavily influenced by upstream **chemical production (especially lime)** and **steam demand.**

Potential improvements ●

There is a potential to reduce chemical burdens in lactic acid production, e.g. by switching from conventional lactic acid to **circular (lime-free) lactic acid.** This could reduce **climate change by 22%**, alongside **particulate matter (19%)**, **acidification (17%)**, and **water use (26%).**

Since steam is a major for PLA, cleaner heat supply materially improves results. Also, when recycled/circular PLA feedstocks are used, the environmental impacts are even lower, driven by eliminating the sugarcane production step and fermentation burdens.

■ Climate Change ■ Particulate Matter ■ Ecotoxicity
■ Resource use ■ Land use

Total environmental impact score of substitution: ●

Legend: ≤ –20%: significant advantage for sustainable alternative | 20% < Δ < +20%: no significant difference | ≥ +20%: significant disadvantage

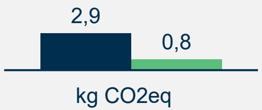
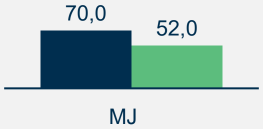
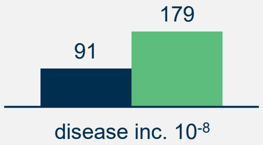
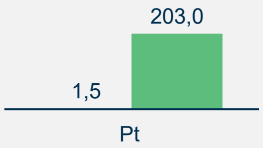
Source: Total Energies - Corbion

Using PEF as a substitute for PET results in a significantly lower environmental impact for climate change and resource use

Quantitative comparison of PET and PEF

Product Category: Textile

Product Category: Packaging – bottles

Impact category	**Climate change**	**Resource use (fossil)**	**Particulate matter**	**Land use**	**Ecotoxicity**
🟦 PET 🟩 PEF					No LCA data available
Qualitative analysis	Including biogenic carbon uptake, PEF shows a significant advantage over PET. For **PET**, climate impact is mainly driven by fossil-based energy use during oxidation, esterification, and polymerization. For **PEF**, the main contributor is fructose production (e.g., wheat-derived high fructose syrup used for FDCA).	**PET** shows significantly higher fossil resource use, as both PTA and MEG are derived from naphtha and natural gas, and production relies on fossil-based energy. Regarding **PEF**, FDCA is from biogenic carbon and MEG is bio-based. Remaining fossil use comes mostly from energy demand in agricultural and conversion processes.	Agricultural activities, particularly fertilizer use and machinery combustion, lead to emissions of NH_3, NO_x, and primary particulates.	Biomass cultivation occupies agricultural land that could otherwise support food production or conservation. Land-use change can also influence biodiversity.	Although no reliable data is available on this impact category. Fertilizer and pesticide application in feedstock cultivation can increase ecotoxicity burdens in soil and water. Emissions of nitrate, phosphate, and persistent agrochemicals contribute to these impacts.
Substitution score	🟢	🟢	🔴	🔴	🔴

Legend: 🟩 ≤ –20%: significant advantage for sustainable alternative 🟧 20% < Δ < +20%: no significant difference 🟥 ≥ +20%: significant disadvantage

Source: PEF in Focus: Life Cycle Assessment of a Next-Gen Biopolymer, Puente A., et al. (2025) (paper currently under review).

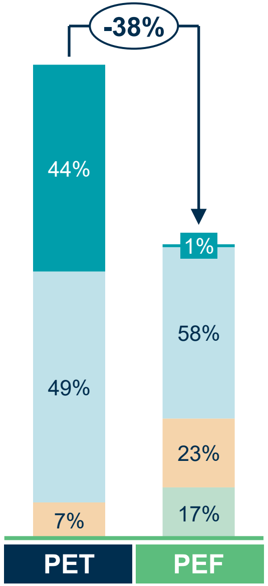
PEF has a significantly lower environmental footprint compared to PET; with room left for further improvements in PEF production

Quantitative comparison of PET and PEF single score and additional qualitative assessment

Product Category: Textile

Product Category: Packaging – bottles

Single score[1) [% points]



advantages not included in the single score 🟢

PEF offers several other notable advantages, including lower impacts related to **mineral and metal resource use and ozone depletion**. PEF also offers **performance benefits** and potential for **lightweighting.**

PEF its biogenic carbon content provides an end-of-life benefit: when incinerated, the released CO_2 is of renewable origin and does not contribute to net GWP, unlike PET.

Also, current PET collection infrastructure can distinguish PEF from PET, making separate **PEF recycling** technically feasible as volumes increase.

Uncertainties 🟠

The environmental performance of PEF is subject to several uncertainties, especially regarding feedstock origin, agricultural practices, and regional variability. Even when identical conversion technologies are used, the carbon footprint and fossil resource depletion indicators can vary substantially depending on crop type, fertilizer intensity, land productivity, and local energy mixes.

Significant disadvantages not included in the single score 🔴

PEF shows a significant disadvantage in **water use**, mainly driven by bio-MEG production. However, this impact category is characterized by high uncertainty as it is location specific.

Potential improvements in production 🟢

Because fructose production contributes around 67% of PEF's total environmental impact, improvements in agricultural practices and the use of certified sustainable or secondary biomass could substantially reduce its footprint.

Significant additional gains can be achieved through **regenerative farming**, process decarbonization, and better integration into advanced recycling systems, all of which would strengthen PEF's overall environmental performance.

🟦 Climate Change
🟧 Particulate Matter
🟦 Resource use
🟩 Land use

Total environmental impact score of substitution: 🟢

Legend: 🟩 ≤ –20%: significant advantage for sustainable alternative 🟧 20% < Δ < +20%: no significant difference 🟥 ≥ +20%: significant disadvantage

1) Single score excludes ecotoxicity score due to data availability.

Source: PEF in Focus: Life Cycle Assessment of a Next-Gen Biopolymer, Puente A., et al. (2025) (paper currently under review).

Using bio-MPA as a substitute for Phthalic Anhydride may result in a significantly lower environmental impact for climate change and resource use

Product Category: Paints & varnishes

Qualitative comparison of phthalic anhydride and bio-MPA per impact category

Impact category	**Climate change**	**Resource use (fossil)**	**Particulate matter**	**Land use**	**Ecotoxicity**
Qualitative analysis	The substitution of phthalic anhydride by bio-based maleic phthalic anhydride (bio-MPA) leads to a significantly lower climate change impact, based on preliminary cradle-to-grave data from a pilot-scale project $^{1)}$. **Bio-MPA** benefits from biogenic carbon uptake during biomass growth, which offsets part of the greenhouse gas emissions associated with cultivation and processing. In contrast, **phthalic anhydride** is fully fossil-based, with climate impacts dominated by fossil feedstock extraction, aromatics production, and oxidation processes.	**Phthalic anhydride** shows higher fossil resource use, as it is produced from fossil aromatic feedstocks and fossil energy inputs along the petrochemical chain. **Bio-MPA** generally shows lower fossil resource use, because the carbon backbone originates from biomass; remaining fossil resource use is mainly linked to agricultural inputs (e.g., fertilizer production), processing energy, and transport.	The substitution of phthalic anhydride by bio-based maleic phthalic anhydride (bio-MPA) most probably leads to higher particulate matter impact. The particulate matter impact of bio-MPA is mainly driven by fertilizer-related emissions and fuel combustion from agricultural field operations associated with biomass feedstock cultivation.	Land use is driven by the need for agricultural land for biomass production. In contrast, phthalic anhydride production relies on fossil aromatics and industrial processing, with negligible land occupation.	Ecotoxicity impacts are primarily linked to pesticide use and nutrient emissions during biomass cultivation, leading to emissions to soil and water compartments.
Substitution score	🟢	🟢	🔴	🔴	🔴

Legend: Significant advantage for sustainable alternative | No significant difference | Significant disadvantage

Bio-MPA shows a potential climate advantage over phthalic anhydride; however, production scale-up and full LCA confirmation are needed

Product Category:
Paints & varnishes

Extended qualitative comparison of phthalic anhydride and bio-MPA

Other significant advantages not included in the qualitative analysis 🔴

Potentially there is an additional environmental benefit from reduced material demand, as bio-MPA enables equivalent or improved performance compared to phthalic anhydride.

Bio-MPA is designed as a functional equivalent to phthalic anhydride, enabling substitution without major reformulation or additional processing steps. This avoids extra environmental burdens linked to redesign or multilayer solutions.

Potential improvements 🟢

Process optimization and scale-up are expected to improve energy efficiency and yields, potentially reducing climate and other environmental impacts.

Feedstock optimization (e.g. sourcing from lower-impact or residual biomass streams) could further reduce land use and agriculture-related impacts.

Integration with renewable energy in production could strengthen the climate benefit relative to fossil phthalic anhydride.

Uncertainties 🟠

The qualitative analysis is based on preliminary pilot-scale cradle-to-grave climate change data, not on a full multi-impact LCA.

Climate impact may differ at commercial scale as scale-up effects (energy efficiency, yields) may change the environmental impact.

Additional data from industrial-scale production are required to robustly quantify environmental impacts.

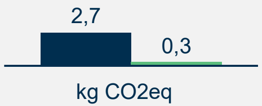
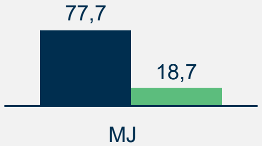
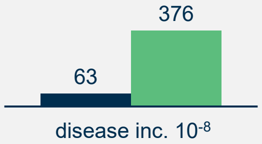
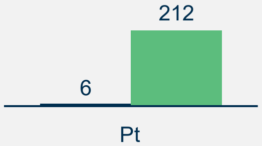
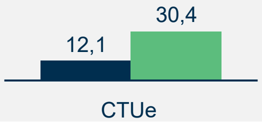
Total environmental impact score of substitution: 🟢

Legend: Significant advantage for sustainable alternative | No significant difference | Significant disadvantage

Using PLA as a substitute for EVA results in a significantly lower environmental impact for climate change and resource use1)

Quantitative comparison of EVA and PLA per impact category

Product Category: Paints & varnishes

Impact category	**Climate change (incl. biogenic carbon uptake)**	**Resource use (fossil)**	**Particulate matter**	**Land use**	**Ecotoxicity**
■ EVA 🟩 PLA					
Qualitative analysis	Including biogenic carbon uptake, PLA represents a climate-change advantage for bio-based alternatives for ethylene vinyl acetate (EVA). **EVA** is produced from fossil ethylene and vinyl acetate monomer, with climate impact driven by fossil feedstock use and fossil energy in monomer production and polymerization. For **PLA**, climate impact is primarily driven when using chemicals, sugar and steam.	PLA has a significantly lower fossil resource use than EVA. **EVA** relies entirely on fossil-derived monomers and fossil energy throughout its value chain. **PLA** has much lower fossil resource use, because the carbon in the polymer is biogenic (from sugars). Remaining fossil demand is mainly linked to steam and electricity use and upstream chemical and agricultural inputs, such as fertilizer production and energy use during fermentation and polymerization.	The particulate matter impact of PLA is driven by fertilizer-related emissions and combustion emissions from field operations, mainly associated with sugar production (66%) and chemical production (28%).	The land use impact of PLA is dominated by sugar production (93%), making this impact highly sensitive to crop yields, allocation choices, sugar recovery efficiency, and conversion efficiency.	PLA shows higher ecotoxicity risk than EVA due to fertilizer and pesticide use and nutrient emissions during feedstock cultivation, affecting soil and water compartments.
Substitution score	🟢	🟢	🔴	🔴	🔴

Legend: 🟩 ≤ –20%: significant advantage for sustainable alternative 🟨 20% < Δ < +20%: no significant difference 🟥 ≥ +20%: significant disadvantage

1) PLA is a low-TRL, bio-based option to replace vinyl binders and its costs may drop with scale. The substitution of EVA by PLA is used here as a proxy for bio-based substitutes.

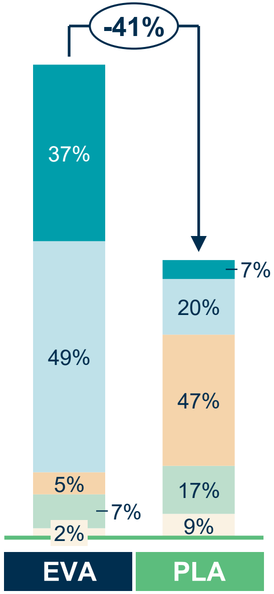
Source: Total Energies – Corbion

PLA has a significantly lower environmental footprint compared to EVA; with room left for further improvements in PLA production

Quantitative comparison of EVA and PLA single score and additional qualitative assessment

Product Category:
Paints & varnishes

Single score [% points]



Significant advantages not included in the single score ●

Ozone depletion and minerals/metals resource use can be favorable for PLA depending on the energy/chemicals profile.

PLA has an additional end-of-life accounting benefit when biogenic carbon is considered: CO_2 released on incineration is renewable in origin (biogenic), unlike EVA's fossil carbon which increases net GWP.

PLA has a defined route to **chemical recycling back to lactic acid**, enabling recycled-content grades with strong climate performance when biogenic carbon is included.

Uncertainties

Impact category uncertainty is typically higher for categories tied to agricultural emissions and modelling choices (e.g., particulate matter, land use and ecotoxicity), and results should be interpreted with attention to dataset representativeness and regional validity.

PLA is made of starch. The EcoInvent impact calculations of starch are based on older cultivation data (Germany, 2003), meaning improvements in farming practices are not fully reflected, making the estimate conservative.

Significant disadvantages not included in the single score ●

PLA has a water use disadvantage. Water use contributions come mainly from **lactic acid production** and **sugar production**. However, it should be noted that water use is location-specific.

PLA's climate impact is heavily influenced by upstream **chemical production (especially lime)** and **steam demand.**

Compared to EVA, PLA can show lower flexibility, impact resistance, and hydrolytic stability, with higher sensitivity to moisture and alkaline conditions, and may require adapted processing or additives.

Potential improvements ●

There is a potential to reduce chemical burdens in lactic acid production, e.g. by switching from conventional lactic acid to **circular (lime-free) lactic acid** . This could reduce **climate change**, alongside **particulate matter**, **acidification,** and **water use.**

Since steam is a major contributor for PLA, cleaner heat supply materially improves results.

When recycled/circular PLA feedstocks are used, the environmental impacts are even lower, driven by eliminating the sugarcane production step and fermentation burdens.

■ Climate Change ■ Particulate Matter ■ Ecotoxicity
■ Resource use ■ Land use

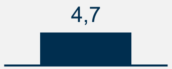
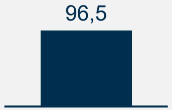
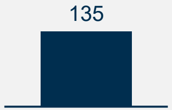
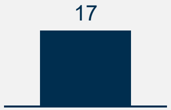
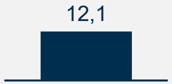
Total environmental impact score of substitution: ●

Legend: ≤ –20%: significant advantage for sustainable alternative | 20% < Δ < +20%: no significant difference | ≥ +20%: significant disadvantage

Recycled PU foam shows a potential climate advantage over virgin PU foam; however, production scale-up and full LCA confirmation are needed

Product Category: Furniture

Qualitative comparison of virgin PU foam and recycled PU foam per impact category

Impact category	**Climate change**	**Resource use (fossil)**	**Particulate matter**	**Land use**	**Ecotoxicity**
■ PU foam	 4,7 kg CO2eq	 96,5 MJ	 135 disease inc. 10^{-8}	 17 Pt	 12,1 CTUe
Qualitative analysis	Based on preliminary data of pilot-scale recycling of PU foam the substitution of virgin PU foam with recycled PU foam leads to a lower climate change impact. Recycled PU foam benefits from avoided production of primary polyols and isocyanates. Base case analysis shows that pyrolysis of waste mattresses saves approximately 526 kg CO2 eq/tonne of mattress waste. (IPCC 2013 GWP 100a).	Pyrolysis of waste mattresses saves approximately 5.1 GJ (= 24% savings) Cumulative Energy Demand (CED - version 1.11) compared to incineration. Recycled PU foam benefits from avoided fossil feedstock extraction,. In contrast, virgin PU foam is fully fossil-based, with climate impacts dominated by petrochemical feedstock extraction, polyol synthesis, and energy-intensive foaming processes.	There is limited data available on particulate matter for recycled PU foam, as this technique is still in pilot stage. For virgin PU foam, the particulate matter is found at 135 * 10^-8 Disease inc.	Virgin PU foam production indirectly drives land use impacts through fossil resource extraction and associated infrastructure. Recycled PU foam avoids these upstream impacts but may require collection and sorting systems, which have minor land use implications compared to primary production.	Among the products analyzed in this study, virgin PU foam shows relatively high ecotoxicity, primarily due to the hazardous chemicals involved in its production. For chemically recycled PU foam, the situation is more complex. Certain recycling methods may require chemical treatments or additives to restore material properties. However, since no fully developed and standardized technique currently exists, there is insufficient data to enable a robust comparison of ecotoxicity impacts.
Substitution score	🟢	🟢	🟠	🟠	🟠

Legend: 🟩 Significant advantage for sustainable alternative 🟧 No significant difference 🟥 Significant disadvantage

PU foam recycling process to be scaled as chemical recycling

Product Category: Furniture

Extended qualitative comparison of PU foam and recycled PU foam

Other significant disadvantages not included in the qualitative analysis 🔴

Currently, no commercial plants for PU rigid foam recycling are in operation. PU rigid foams are thermoset materials, meaning they cannot be remelted and reformed into new products. This characteristic results in an inherent deterioration of material properties during mechanical recycling processes such as shredding.

Consequently, rigid foams can only be mechanically recycled a limited number of times, making this approach unsuitable as a long-term alternative within the plastic life cycle.

In contrast, chemical recycling offers the potential for PU rigid foam to be recycled an unlimited number of times, provided that efficient and scalable technologies are developed.

Potential improvements 🟢

Process optimization during scale-up of new chemical recycling processes are expected to improve energy efficiency and yields, potentially reducing climate and other environmental impacts.

Integration with renewable energy in production could strengthen the climate benefit relative to fossil phthalic anhydride.

Uncertainties 🟡

The qualitative analysis presented here is based on preliminary pilot-scale and cradle-to-grave climate change data rather than a full multi-impact LCA. As a result, several uncertainties remain:

- Data limitations: Additional data from industrial-scale production are required to robustly quantify non-climate impacts such as ecotoxicity, resource depletion, and human health.
- Alternative pathways for data: Pyrolysis of old PU mattresses shows potential to significantly reduce CO_2 emissions, but its environmental trade-offs require further assessment.
- Potential trade-offs: While recycling reduces climate and resource impacts, it may introduce new challenges, including emissions from transportation of post-consumer waste, use of solvents or additives during reprocessing, and possible limitations in foam quality or performance.

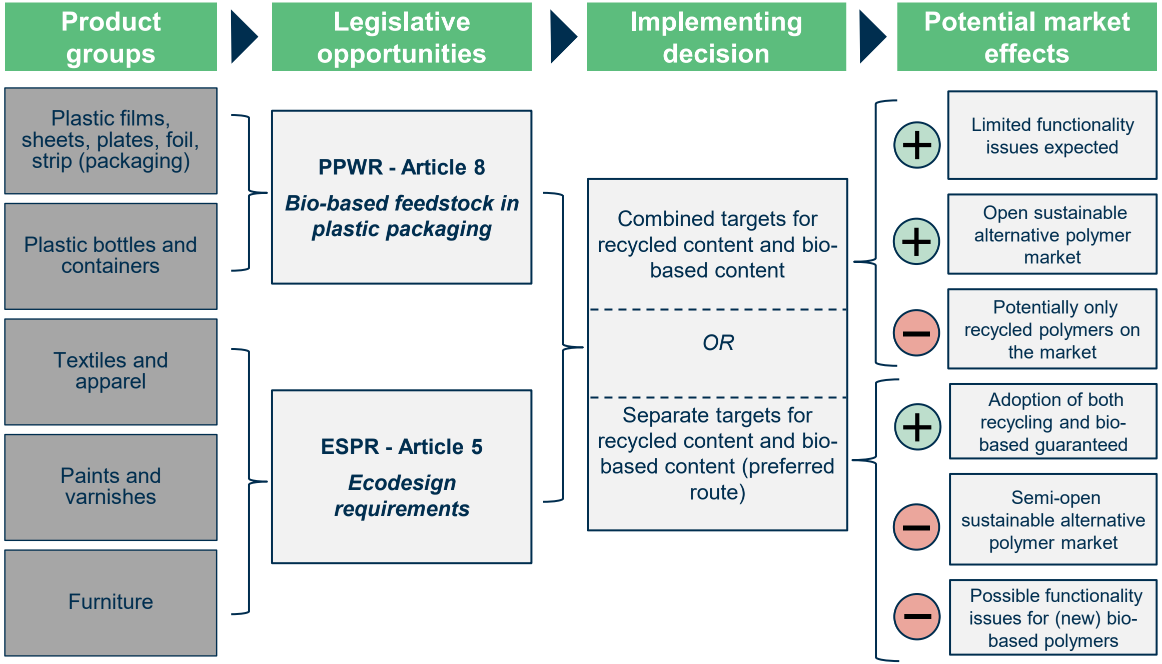
Total environmental impact score of substitution: 🟢

Legend: 🟩 Significant advantage for sustainable alternative 🟨 No significant difference 🟥 Significant disadvantage

D Policy analysis and opportunities

A key policy decision is required on whether to implement combined or separate targets for recycled and bio-based content at product-group level

Overview of product groups, legislative entry points, and expected market effects of mandatory sustainable carbon targets



Product groups

- Plastic films, sheets, plates, foil, strip (packaging)
- Plastic bottles and containers
- Textiles and apparel
- Paints and varnishes
- Furniture

Legislative opportunities

PPWR - Article 8

Bio-based feedstock in plastic packaging

ESPR - Article 5

Ecodesign requirements

Implementing decision

Combined targets for recycled content and bio-based content

OR

Separate targets for recycled content and bio-based content (preferred route)

Potential market effects

- \+ Limited functionality issues expected
- \+ Open sustainable alternative polymer market
- − Potentially only recycled polymers on the market
- \+ Adoption of both recycling and bio-based guaranteed
- − Semi-open sustainable alternative polymer market
- − Possible functionality issues for (new) bio-based polymers

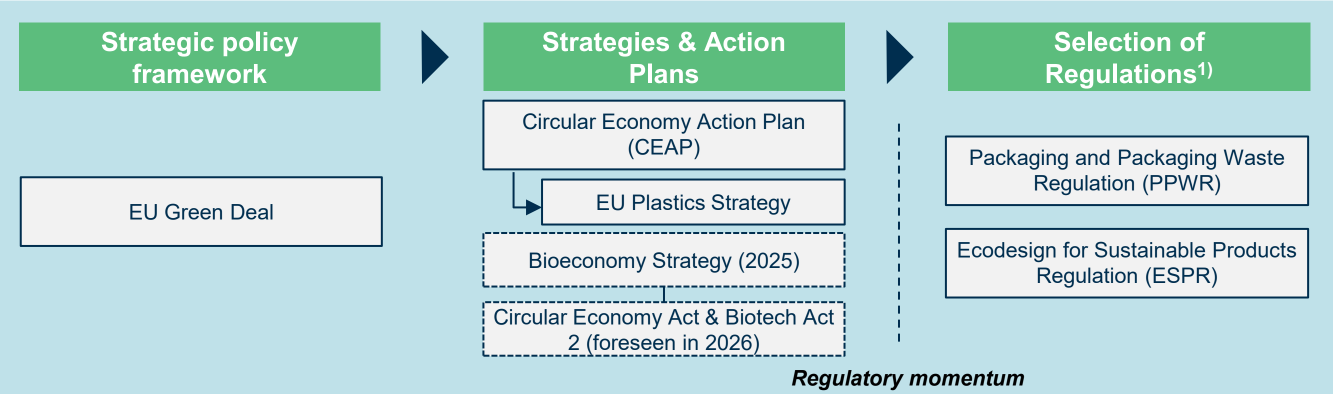
Considerations and evaluation

- The **PPWR** (2025/40) and **ESPR** (2024/1781) offer opportunities to implement mandatory targets on sustainable carbon content in specific product groups.
- A **key policy decision** needs to be made between combined or separate targets for recycled and bio-based content.
  - **Separate targets** guarantee entry of bio-based polymers in the market. However, it may influence polymer prices due to a semi-open market.
  - A **combined target** creates an open market for all sustainable polymers but risks favoring recycled polymers only (because of its availability on the market) and prevents entry of bio-based feedstock on the market.
  - **R&D** may be required to meet product functionality when applying (new) bio-based sustainable polymer alternatives in some of the product groups, which may require a longer transition time toward the use of it.
- **To make an informed decision** on the use of separate targets for recycled and bio-based polymers, it is recommended to address the considerations for this option and **identify the need of complementary policies to ensure a stable market for all sustainable polymers.**

Sources:
PPWR Regulation - EU - 2025/40 - EN - EUR-Lex
ESPR Regulation - EU - 2024/1781 - EN - EUR-Lex

Regulatory momentum is in place and the PPWR and ESPR provide timely entry points to introduce mandatory targets on sustainable carbon content

The regulatory momentum, impact and specific opportunities created by policy frameworks, strategies and EU legislation



Strategic policy framework

EU Green Deal

Strategies & Action Plans

Circular Economy Action Plan (CEAP)

EU Plastics Strategy

Bioeconomy Strategy (2025)

Circular Economy Act & Biotech Act 2 (foreseen in 2026)

Selection of Regulations[1)]

Packaging and Packaging Waste Regulation (PPWR)

Ecodesign for Sustainable Products Regulation (ESPR)

Regulatory momentum

EU legislation	Impact	Opportunity
Packaging and Packaging Waste Regulation (PPWR)	Enforces mandatory recycled content and recyclability standards, reshaping packaging design and supply chains to meet EU circular economy goals.	Setting (additional) targets for both recycled content and/or bio-based content for packaging categories via delegated acts and/or periodical revision moments.
Eco-Design for Sustainable Products Regulation (ESPR)	Mandates eco-design for durability, reparability, and recyclability, introducing Digital Product Passports to ensure traceability and transparency across product life cycles.	Setting targets for both recycled and/or bio-based content for product groups via delegated acts and / or periodical revision moments.

Notes:

- The EU Green Deal aims for climate neutrality by 2050 and drives legislation impacting sustainable carbon. The EU Plastics Strategy focuses on reducing waste and improving recycling, now translated into binding laws.
- The Bioeconomy Strategy (27 November 2025) enables the integration of bio-based targets into existing regulations (PPWR and ESPR) by promoting their inclusion in Ecodesign requirements, while the Circular Economy Act and the Biotech Act 2 (2026) will further embed these targets in specific product legislation.
- Both the PPWR and ESPR offer opportunities to include sustainable alternative polymer targets (recycled and bio-based) through delegated acts, making this the ideal Regulatory moment to act.
- Under PPWR: packaging (e.g. plastic films, sheets, plates, foil, strip, plastic bottles and containers).
- Under ESPR: product groups (e.g. textiles and apparel, paints and varnishes, furniture).

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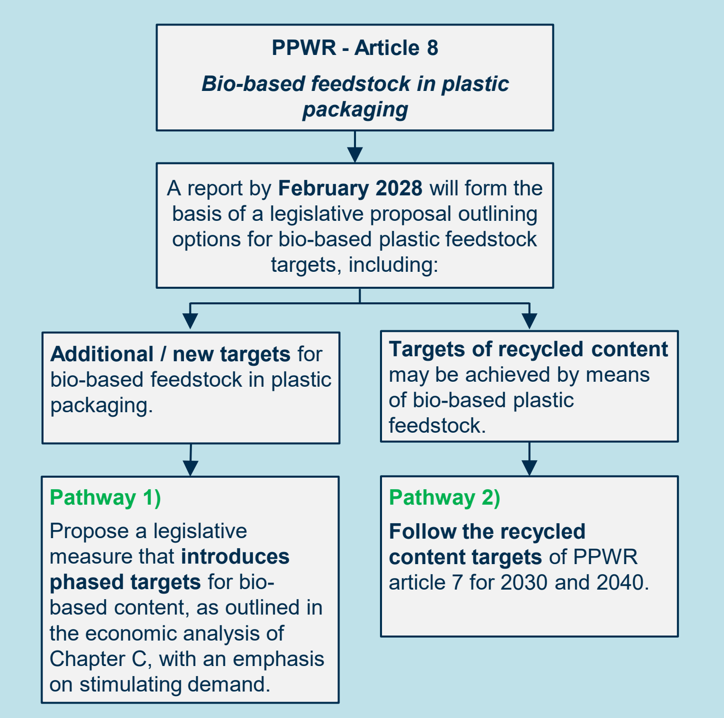
1) **See criteria in appendix F.**
2) Source: EU Green Deal
3) Source: Biotech Act 2
4) Source: Circular Economy Act

Mandatory targets for bio-based content in plastic packaging can be implemented through the PPWR

Legislative pathways and indicative target levels for bio-based alternatives in packaging product groups

Product groups	Sustainable polymer alternative
Plastic films, sheets, plates, foil, strip (packaging)	- **PLA** as a substitute for PP - **Starch** as a substitute for PE-LD
Plastic bottles and containers	- **PEF** as a substitute for PET

Potential legislative pathway for sustainable alternative content targets in packaging (plastic films, sheets, plates, foil, strip, bottles and containers)



PPWR - Article 8

Bio-based feedstock in plastic packaging

A report by **February 2028** will form the basis of a legislative proposal outlining options for bio-based plastic feedstock targets, including:

Additional / new targets for bio-based feedstock in plastic packaging.

Pathway 1)

Propose a legislative measure that **introduces phased targets** for bio-based content, as outlined in the economic analysis of Chapter C, with an emphasis on stimulating demand.

Targets of recycled content may be achieved by means of bio-based plastic feedstock.

Pathway 2)

Follow the recycled content targets of PPWR article 7 for 2030 and 2040.

Regulatory context:

- By 2025, the PPWR offers the opportunity to include targets focusing on recycled materials only.
- The Bioeconomy Strategy, published on November 27th, 2025, includes a goal for bio-based targets in existing PPWR by 2027. Article 8 of the PPWR allows the integration of targets.

Economic conditions:

- For plastic films, sheets, plates, foil, and strips, if the sustainable polymer market solely consists of PLA and starch**, a minimum target of 2.3% for bio-based content** would create a viable production market.
- For plastic bottles and containers, if the sustainable polymer market solely consists of PEF, **a minimum target of 1.7% for bio-based content** would establish a viable production market.

Source: PPWR Regulation - EU - 2025/40 - EN - EUR-Lex

The ESPR enables the implementation of mandatory targets for recycled and bio-based content across defined priority product groups

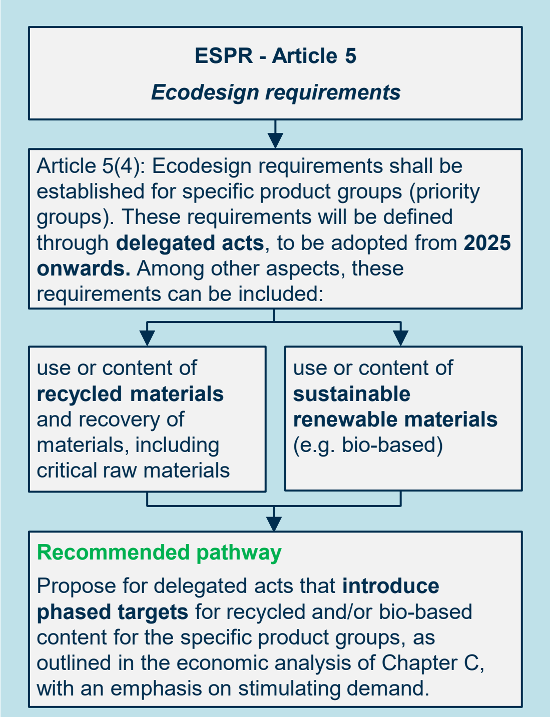
Legislative pathways and indicative target levels for sustainable polymers in product groups defined under the ESPR

Product groups	Sustainable polymer alternative	
Textiles and apparel	- **Recycled PA** as a substitute for PA	- **PEF** as a substitute for PET
Paints and varnishes	- **Bio-MPA** as a substitute for alkyds	- **PLA** as a substitute for vinyl
Furniture	- **Recycled PU** (chemical) as a substitute for PU	

🟦 Recycled

🟩 Bio-based

Potential legislative pathway for sustainable alternative content targets in product groups identified in the ESPR (textiles and apparel, paints and varnishes, furniture)



ESPR - Article 5

Ecodesign requirements

Article 5(4): Ecodesign requirements shall be established for specific product groups (priority groups). These requirements will be defined through **delegated acts**, to be adopted from **2025 onwards.** Among other aspects, these requirements can be included:

use or content of **recycled materials** and recovery of materials, including critical raw materials

use or content of **sustainable renewable materials** (e.g. bio-based)

Recommended pathway

Propose for delegated acts that **introduce phased targets** for recycled and/or bio-based content for the specific product groups, as outlined in the economic analysis of Chapter C, with an emphasis on stimulating demand.

Regulatory context:

- By 2025, the ESPR can include targets for recycling and/or bio-based materials in specific product groups.
- The Bioeconomy Strategy (2025), can include goals for bio-based targets for product groups (addressed in ESPR).
- By 2027-2028, targets will be adopted in the first delegated act on textiles and apparel.

Economic conditions:

- For textiles and apparel, if the sustainable polymer market solely consists of Recycled PA and PEF, **a minimum target of 2.8%** would create a viable production market.
- For paints and varnishes, if the sustainable polymer market solely consists of Bio-MPA and PLA, **a minimum target of 5.4%** would establish a viable production market.
- For furniture, if the sustainable polymer market solely consists of Recycled PU**, a minimum target of 1.2%** would create a viable production market.

Source: ESPR Regulation - EU - 2024/1781 - EN - EUR-Lex

Additional measures are required to support adoption of sustainable carbon, including transition time, investment conditions, input availability and a level playing field

Key market conditions and complementary proposed measures

Market conditions	Proposed measures1)
Adaption time: the market needs sufficient time to adjust and gain experience with the adoption of sustainable alternative polymers. R&D on product functionality may ask for differed transition times.	**Phased targets in PPWR and ESPR:** starting with relatively low (but minimum) targets can already create a viable market while giving the industry time to adapt.
Investment climate: the market requires a predictable financial environment to support the development of sustainable polymers within the EU.	**Sector recommendations for a resilient and circular plastic value chain in the EU**: identify a multitude of improvements, to increase a level playing field (unfair competition from outside EU, EPR scheme harmonization, end of loopholes).
Input materials: to enable polymer recycling, the market should have easy access to waste polymers for the production process.	**End-of-waste:** joint industry recommends to use JRC's recommendation to harmonize and simplify the end-of-waste criteria, which will ensure a level playing field and avoid delays in adoption.
Level playing field: the market needs a level playing field with consistent rules and enforcement for adopting sustainable alternative polymers.	**EU wide enforcement:** current enforcement of (environmental) regulations varies across member states. Ensuring strict and consistent enforcement is essential for a fair and functioning market.

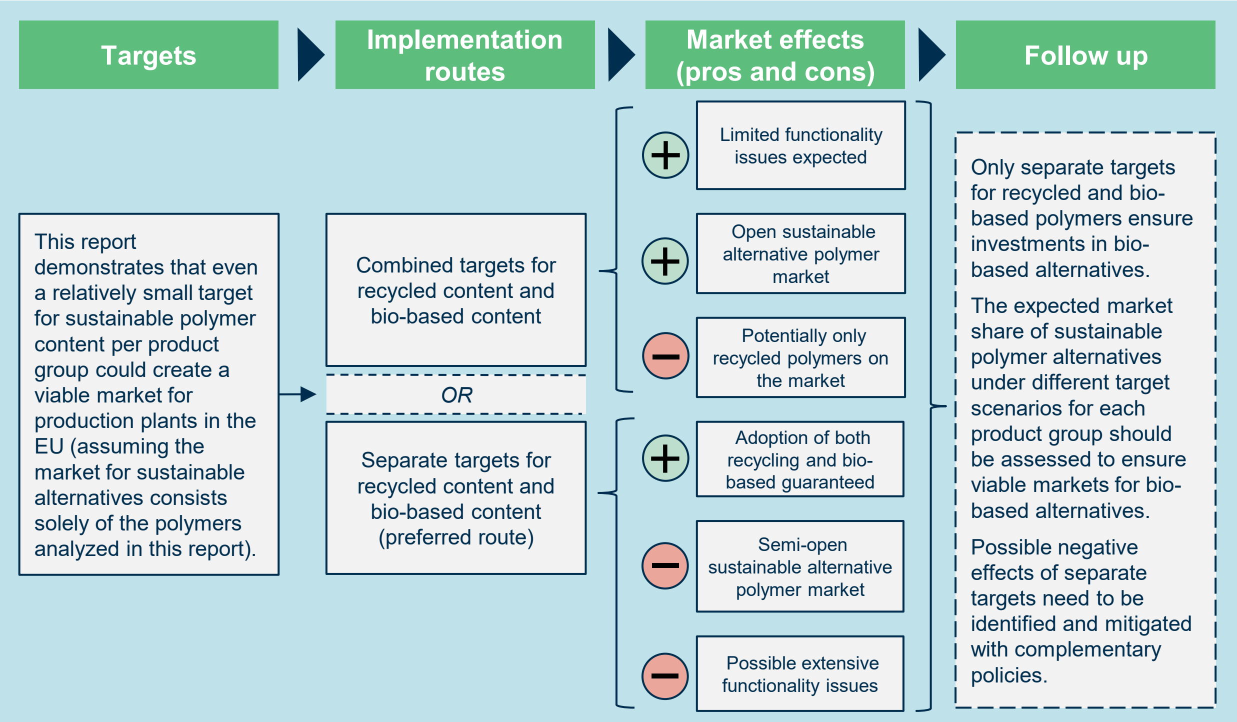
---

1) This is a selection of proposed measured.

Sources: Joint letter from the plastic value chain (04 September 2025);
Recycling industry call for EU wide End of Waste criteria (03 February 2025)

Separate mandatory targets for recycled and bio-based content better safeguard investment in bio-based alternatives than combined targets

Targets, implementation routes and expected market effects of combined and separate targets



Targets ▶ **Implementation routes** ▶ **Market effects (pros and cons)** ▶ **Follow up**

This report demonstrates that even a relatively small target for sustainable polymer content per product group could create a viable market for production plants in the EU (assuming the market for sustainable alternatives consists solely of the polymers analyzed in this report).

Combined targets for recycled content and bio-based content

- + Limited functionality issues expected
- + Open sustainable alternative polymer market
- − Potentially only recycled polymers on the market

OR

Separate targets for recycled content and bio-based content (preferred route)

- + Adoption of both recycling and bio-based guaranteed
- − Semi-open sustainable alternative polymer market
- − Possible extensive functionality issues

Only separate targets for recycled and bio-based polymers ensure investments in bio-based alternatives.

The expected market share of sustainable polymer alternatives under different target scenarios for each product group should be assessed to ensure viable markets for bio-based alternatives.

Possible negative effects of separate targets need to be identified and mitigated with complementary policies.

Notes:

- A combined target for recycled and bio-based content would allow the market to be flexible. However existing recycled polymers are expected to be cheaper and could be an obstacle to the entry of bio-based polymers into the market and not attract investors.
- Separate targets would require the mandatory use of both recycled and bio-based polymers, ensuring investments in bio-based alternatives.
- Bio-based polymers as a substitute may have different properties and functionality challenges that have to be assessed ahead of setting targets and its transition time.
- The impact of pricing due to a semi-open market structure for sustainable alternative polymers should be assessed.
- To guide decision-making, a future analysis of all expected polymer market shares under different target scenarios is recommended to assess potential market reactions and alignment with the Commission's objectives.

E Recommendations

Prioritize textiles and packaging under the ESPR and develop mandatory targets for sustainable carbon content that support both recycled and bio-based pathways to enable effective implementation

Conclusions

Prioritization of product groups:

- **The PPWR and ESPR provide concrete legislative entry points** to introduce binding targets for recycled and/or bio-based content **at product-group level**, through foreseen delegated acts, without requiring changes to the core regulatory frameworks.
- **Textiles and packaging should be prioritized for sustainable carbon substitution** as these product groups show the largest potential climate impact reduction and already fall within the priority scope of the **ESPR**, enabling fast implementation.
  - **Within packaging,** plastic films and bottles can and should be addressed separately under the **PPWR**.
- For **paints & varnishes and furniture**, the sustainable alternative polymers have **lower technological readiness**, limiting substitution potential in the short to medium term. These product groups should therefore receive **lower policy priority.**

Recommendations

Mandatory targets for sustainable carbon content:

- **Translate the identified priority product groups into mandatory targets for sustainable carbon content at product-group level**, using the PPWR and ESPR as legislative entry points, with a stepwise phase-in towards 2050 to provide predictable demand signals that support investment decisions and scale EU production capacity.
- **Consider implementing separate targets for recycled and bio-based content**, reflecting their **complementary roles** in replacing fossil carbon and their different constraints. This will help **safeguard investment in bio-based alternatives** alongside recycling and secure sufficient sustainable carbon supply in the **long term.**
- Ensure **regulatory alignment** across relevant EU instruments and put enabling conditions in place to avoid conflicting incentives, prevent regulatory fragmentation, and enable **effective implementation of targets**.
- Introduce a **robust and transparent LCA methodology** to ensure **fair and comparable assessment** of fossil-based, recycled and bio-based polymers.

Next steps

Further analytical and implementation work:

- **Develop EU-wide legislative implementation pathways for mandatory targets per product group**, using the ESPR and PPWR as the primary instruments.
- **Engage and coordinate key stakeholders** to support pathway design, implementation planning and consistent EU-wide delivery.
- **Further assess expected demand and required volumes per product group under different target scenarios**, extending the analysis to a wider set of polymers and applications and examining technical applicability, feedstock availability, required investments, transition timelines and end-user cost impacts.
- **Define and operationalize enabling conditions**, including EU-wide impact assessment and monitoring, stable financing instruments, responsible biomass sourcing safeguards, protection against unfair competition from outside the EU, and consistent enforcement.

F Appendices

F Appendix: Selection framework

The selection of product groups and sustainable polymer alternatives to be researched is made using a combined volume and multi-criteria analysis

Method for selection product groups and sustainable polymer alternatives

This project began with a broad selection of product groups characterized by a high fossil polymer content. To narrow down the scope for detailed research**, a five-step analytical process was applied**, based on initial insights into these groups, their plastic content, and potential sustainable alternatives. The selection process focused on product groups currently dominated by high-volume fossil-based polymers that offer the greatest potential for sustainable substitution. This approach ensures that subsequent research targets areas with the highest environmental, economic, and regulatory relevance.

Central to this methodology are Step 2 and Step 4, whose results are combined in Step 5 to determine the final set of prioritized product groups and corresponding sustainable polymer alternatives.

1

Inventory of product groups and fossil polymers

Inventories of product groups and fossil polymer are made based on rapports, research papers and expert knowledge. The resulting list of fossil polymers forms the input for the assessment conducted in step 4.

2

Volume analysis of fossil polymers

To maximize impact, the size of each product group determines its substitution potential. A volume analysis of European production is carried out for each polymer group, expressed in polymer content, to estimate the potential substitution volume. This analysis results in a prioritized list of fossil polymers with the highest substitution potential.

3

Inventory of sustainable polymer alternatives

Inventories of sustainable polymer alternatives to the list of fossil based polymers found by step 1 and 2 are compiled using reports, research papers, and expert knowledge. The resulting list of sustainable polymer alternatives forms the input for the assessment conducted in step 4.

4

Assessment of polymers using a multi-criteria decision-making framework

Each sustainable polymer alternative is evaluated against its fossil-based counterpart using three key indicators:

- Carbon footprint reduction
- Cost of the sustainable alternative
- Technical readiness

Each indicator is assigned a weight reflecting its relative importance. The weighted average score for each alternative is then calculated by multiplying indicator scores by their respective weights. An example is provided in the next pages.

5

Selection of product groups

The selection process started with an initial inventory of product groups and fossil polymers

Considered product groups and their fossil content

Product group	Main plastics (fossil-based polymers) used in product groups
Bumpers and bumper parts (CN 8708.10)	PP, ABS, PA
Computers, laptops (CN 8471)	ABS, PMMA (screens), PVC (cables)
Detergents & washing preparations (CN 3402)	PVA
Footwear (CN 6401-6405)	PVC, PUR, EVA
Furniture (CN chapter 94) (9401 seats; 9403 other furniture)	PU foam (slab stock)
Knotted netting (fishing nets, agriculture crop protection) (CN 5608)	PE, PP
Lubricating preparations (Cn 3403)	PE, PP, PA
Mattresses (CN 9404) (9404.21 mattresses of cellular rubber/plastics)	PU foam
Paints/varnishes based on polymers (CN 3208)	PMMA, PUR, PS, SAN, EVA
Plastic bottles and containers (CN 3923,30)	PET, HDPE, PP
Plastic films, sheets, plates, foil, strip (CN 3920 non-cellular/non-laminated, and CN3921 other)	LDPE, PP, PET, PVC
Plastic floor coverings (CN 3918)	Vinyl, PVC
Plastic profiles for construction (CN 3925)	PVC
Plastic-based insulation materials (Cn 3903, 3909)	EPS, PUR foams
PVC pipes and hoses (CN 3917.23)	PVC
Seats used for motor vehicles (CN 9401.20)	PUR
Small household appliances (CN 8509 and 8516)	ABS, PP, PS
Textiles/Apparel (CN Chapters 50-63)	PET (polyester), PA (nylon), PP (nonwovens, carpets)
Toys (CN 9503)	ABS, PP, HDPE, LDPE
TV's, Monitors (CN 8528)	ABS, PVC
Tyres (CN Chapter 40, esp. 4011 (new pneumatic tyres), 4012 (retreaded tyres))	SBR, BR, PA, resins

The product groups are based on the categories of the European plastics conversion matrix of The Circular Economy for Plastics$^{1)}$ (2024)

Inventory of product groups and fossil-based polymers

1

2

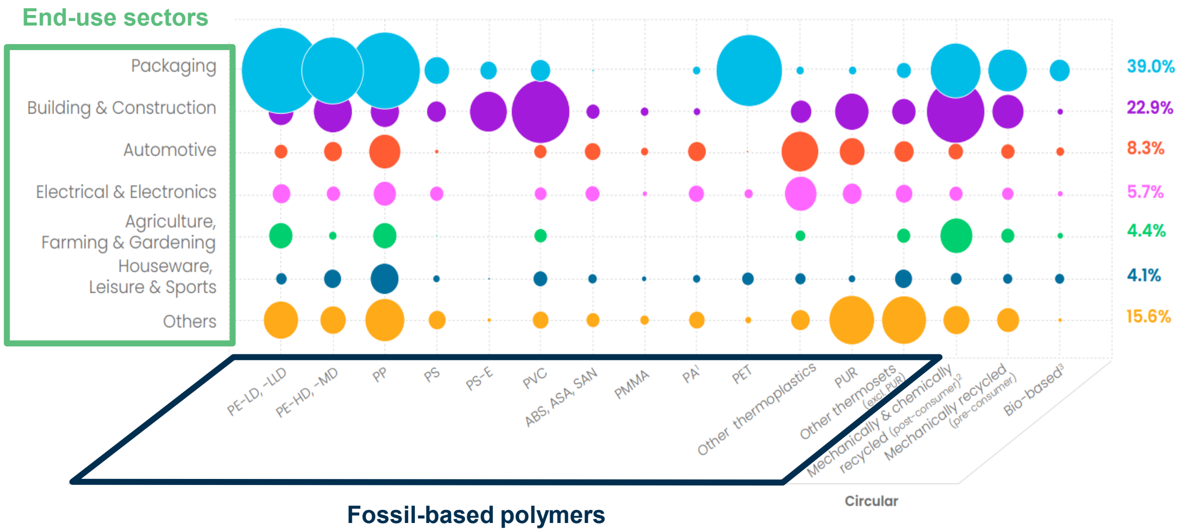
3

4

5

The product groups are derived from the European Plastics Conversion Matrix as defined in *The Circular Economy for Plastics* (2024).

This matrix categorizes polymers (bottom) according to their end-use sectors (left).



From end-use sectors to product groups

To align the analysis with EU policy and regulatory frameworks, the identified end-use sectors are translated into legally defined product groups.

This ensures that the outcomes of the assessment can be directly incorporated into EU legislation, such as the Ecodesign for Sustainable Products Regulation (ESPR), and can therefore support future regulatory implementation and policy development.

For product groups that are not yet precisely defined within EU legislation, or where definitional flexibility remains, globally recognized trade codes (HS/CN codes) are applied as supporting indicators to ensure consistent and transparent classification across markets.

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1) Carbon-containing polymers used in the Circular Plastics report van Plastics Europe, supplemented with synthetic fibers and specialty chemicals.
Source: Circular Economy Report , Plastics Materials Flow, Automotive

Based on volume analysis of polymer content of European production, there are 9 product groups that are indicated as significant¹⁾

Volume analysis of product groups

1
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3
4
5

Product group	Fossil polymer content [Mt]
Plastic films, sheets and foils	4,8
Textiles and apparel	3,7
Tyres	2,0
Paints/varnishes based on polymers	1,5
Furniture	1,5
Plastic bottles and containers	1,2
Small household appliances	1,2
Bumpers and bumper parts	1,0
PVC pipes and hoses[2)]	1,0

Selection of bulk segments with high impact

The list of product groups was narrowed down to nine product groups through a volume analysis of polymer content in European production. Only product groups with a fossil polymer content exceeding 1 million tons (Mt) were retained, representing the key bulk segments with the highest potential impact for sustainable substitution.

The table on the left presents the nine product groups meeting this threshold. These figures highlight where fossil-based polymers dominate the European plastics market, providing a basis for prioritizing sustainability efforts.

Fossil polymer content calculations

The fossil polymer content for each product group is calculated using the following formula:

$$\text{Fossil Polymer Content [Mt]} =$$
$$\text{Annual European Production Volume [Mt]} \times \text{Average Fossil Polymer Content [vol. \%]}$$

The main data inputs used for this calculation are listed on the next slide.

---

1) Product groups that where part of the study have a annual fossil polymer content under 1 Mt : Plastic-based insulation materials; Lubricating preparations; Mattresses; Computers, laptops; Knotted netting (fishing nets, agriculture crop protection); Plastic floor coverings; Detergents & washing preparations; Plastic profiles for construction; Toys; Footwear; Seats used for motor vehicles; TV's and Monitors

Sources for volume analysis of product groups

Overview of sources used for calculating the fossil polymer content per product group

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Product group	Fossil polymer content [Mt]	Sources
Plastic films, sheets and foils	4,8	Eurostat
Textiles and apparel	3,7	Textiles and the environment: the role of design in Europe's circular economy | Publications | European Environment Agency (EEA), Share of synthetic fibres and yarns in EU industrial textiles use | Textiles | Circularity Metrics Lab (EEA)
Tyres	2,0	Eurostat, ETRMA_Report_WEB_SPREADS-1.pdf
Paints/varnishes based on polymers	1,5	Prodcom, Eurostat, Paint and Varnish Market: Production, Suppliers, Industry
Furniture	1,5	Eurostat, Indexbox, Industry Data – EUROPUR, Europe PU flex foam output falls 2.7pc in 2024 | Latest Market News
Plastic bottles and containers	1,2	20240403-APPLiA-print-version-final.pdf
Small household appliances	1,2	Eurostat
Bumpers and bumper parts	1,0	Eurostat
PVC pipes and hoses[2)]	1,0	Eurostat

For each of the by volume analysis selected product groups, their fossil polymers and sustainable alternatives are identified

Overview of fossil polymers and sustainable alternatives assessed in multi-criteria decision-making framework

Fossil polymer 1)	Sustainable alternative
PET	Recycled PET
	PEF
PE-HD	Recycled PE-HD
	Bio-based PE-HD
PE-LD	Bio PE
	Starch
	Recycled PE-LD
PA	Recycled PA
	Bio-based PA
PP	Bio-PP
	PLA
PUR	Bio-based PUR
	Natural latex/rubber
	Recycled PU foam
	Mycelium

Fossil polymer 1)	Sustainable alternative
PVC	Recycled PVC
	Bio-based EVA
PS	PHA
	PLA
	Mycelium
ABS/ASA/SAN	Recycled ABS
	Bio-based ABS
	PHA
	PLA
PMMA	Recycled PMMA
	Bio-based PMMA
Textile fibres	Cellulose acetate
	PEF
Resin in paints/varnishes (PA)	Bio-MPA
Resin in paints/varnishes (EVA)	PLA

---

1) This list highlights the polymers that represent the largest share of material content within the selected product groups on the previous page.

A multi-criteria decision framework is used to assess each alternative is on three indicators: reduction of carbon footprint, cost of the sustainable alternative and its technical readiness

Explanation of indicators

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Reduction potential carbon footprint

Definition: CO_2(eq) reduction per ton, the difference in emissions between the fossil polymer and the sustainable alternative.

Explanation: Indication of the climate benefit achieved through substitution.

Data Sources: Existing emissions data, such as LCAs of polymers and sustainable alternatives.

Importance of indicator: 2/3

Score	Explanation	Metric: Reduction of CO_2eq [ton/ton]
1	Pyrolysis / gasification	<1,5
2	Mechanical / bio-based	1,5 – 3
3	Bio-based / highly efficient	>3

Cost of sustainable alternative compared to fossil polymer

Definition: Estimated additional cost of the sustainable alternative compared to the fossil polymer.

Explanation: The additional cost represent the additional expense for consumers. Actual prices may be higher due to marketing-driven green premiums or fluctuation in oil prices. Energy and labor costs for recycling are excluded, as these cannot be reliably estimated. Additionally, the EPR influences the gross margin on recycling.

Data Sources: Fossil polymer prices from Plastics Polymer Prices; expert judgement on the production cost estimate of sustainable alternatives

Importance of indicator: 2/3

Explanation	Metric: Relative price per ton [%]
Alternative is more expensive	> 125%
Alternative has similar price	75% - 125%
Alternative is cheaper	<75%

Technical readiness

Definition: Technology Readiness Level (TRL) according to European guidelines

Explanation: Only technologies with TRL 6 or higher are considered, as those below this level are unlikely to reach the market and often lack reliable data. Technologies at TRL 6 typically need 3 to 5 years to reach production scale, though policy support can stimulate investments and development more rapidly.

Data Sources: Current production facility capacity as an indicator of TRL; EU project documentation, company reports, technology platforms and experts.

Importance of indicator: 1/3

Explanation	Metric: TRL
6) Integrated prototype[1],7) System prototype[2]	6,7
8) Commercially demonstrated and definitive technique available	8
9) Commercially scaled in relevant size	9

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1) tested in a relevant environment. 2) in operational environment

Each sustainable alternative is given a score on each criteria of the multi-criteria decision-making framework, based on expert knowledge

Example slide scoring for fossil polymer PET and it’s sustainable

	Indicator	Importance of indicator [1]	rPET		PEF	
1						
2	Reduction potential carbon footprint [CO2eq/ton]	2	2	Significant reduction in carbon footprint compared to virgin PET because recycling avoids most upstream emissions from raw material extraction and polymerization.	3	Uses bio-based feedstock (e.g., bio-ethylene glycol from sugarcane), reducing fossil carbon input. However, production still involves energy-intensive processes and land-use impacts.
3	Cost of alternative compared to fossil polymer [€/ton]	2	2	Often cost-competitive or slightly higher than PET, depending on recycling infrastructure and feedstock availability. Availability of rPET is expected to increase due to recycling targets in the EU.	2	Techno-economic analyses provide the first step in determining the viability of PEF showing it could be economically viable at the forecast of PEF market prices.
4	Technical maturity (TRL)	1	3	TRL 9 – fully commercialized and widely used in packaging and textiles.	2	Demo/pilot plants operational; first commercial FDCA plant expected soon. Is commercially available but not yet widely adopted at full market scale.
5	**Weighted score [2]**		**11**		**12**	

[1] The importance weight is indicated according to: ① = low, ② =medium ③ = high.

[2] Calculated as: (single score * importance score); With maximum weighted score: 15.

Sources: Polyethylene furanoate: technoeconomic analysis of bio-based production (2023)

First stage evaluation of polymer alternatives: carbon footprint, cost, and technical readiness (1/3)

Explanation of the initial scoring of the fossil polymer and its sustainable alternative

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Fossil polymer [1]	Sustainable alternative	Score	Explanation
PET	Recycled PET	11	rPET significantly lowers carbon footprint, is generally cost-competitive though sometimes slightly pricier, and has a fully mature industrial processes.
	PEF	12	PEF is biobased, remains more expensive due to high production costs, is still in early commercialization stages but industrially scaled.
PE-HD	Recycled PE-HD	9	PE-HD recycling is mainly done mechanical and can be done chemical, it outperforms virgin HDPE in footprint, has a similar price and has a fully mature industrial processes.
	Bio-based PE-HD	10	Alternative is biobased, limitedly available, meaning it is more expensive and commercially demonstrated and definitive technique available.
PE-LD	Bio-based PE-LD	10	Alternative is biobased, fully mature technologically, but remains more expensive than fossil LDPE.
	Starch	13	Alternative is biobased and biodegrade but suffers from weaker mechanical performance, commercially scaled in relevant size.
	Recycled PE-LD	8	Additional to recycled PE-HD quality is significantly lower due to multilayer pollution.
PS	PHA	10	Alternative is biobased, higher price, process demonstrated and definitive technique available.
	PLA	10	Alternative is biobased, higher price, process demonstrated and definitive technique available.
	Mycelium	10	Alternative is biobased, higher price, process demonstrated and definitive technique available.
PA	Recycled PA	15	Very efficient recycling, lower price, process demonstrated and definitive technique available.
	Bio-based PA	11	Alternative is biobased, similar price, low TRL level (6,7).

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[1] This list highlights the polymers that represent the largest share of material content within the selected product groups.

First stage evaluation of polymer alternatives: carbon footprint, cost, and technical readiness (2/3)

Explanation of the initial scoring of the fossil polymer and its sustainable alternative

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Fossil polymer [1)]	Sustainable alternative	Score	Explanation
PP	Bio-based PP	9	Alternative is biobased, higher price, limited production, in early technical maturity.
	PLA	10	Alternative is biobased, higher price, moving from niche towards commercially scaled production.
PVC	Recycled PVC	15	Very efficient recycling, lower price and commercially scaled in relevant size.
	Bio-based EVA	12	Alternative is biobased, applicable in “soft” PVC products e.g. shoe soles, similar price, and commercially demonstrated and definitive technique available.
ABS/ASA/SAN	Recycled ABS	13	Efficient recycling, has a lower price and is commercially scaled in relevant size.
	Bio-based ABS	9	Alternative is biobased, has as higher price, most technologies remain at pilot or early demonstration level.
	PHA	12	Alternative is biobased, has a similar price and demonstrated and definitive technique available.
	PLA	12	Alternative is biobased, has a similar price and demonstrated and definitive technique available.
PUR	Bio-based PUR	9	Alternative is biobased, has a higher price and low TRL level (6,7).
	Natural latex/rubber	13	Alternative is biobased, has a similar price and is commercially demonstrated and definitive technique available.
	Recycled PU foam	10	Mechanical/chemical recycling, similar price, process demonstrated and definitive technique available.
	Mycelium	10	Alternative is biobased, has a higher price is applicable in limited applications, and demonstrated and definitive technique available.

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1) This list highlights the polymers that represent the largest share of material content within the selected product groups.

First stage evaluation of polymer alternatives: carbon footprint, cost, and technical readiness (2/3)

Explanation of the initial scoring of the fossil polymer and its sustainable alternative

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Fossil polymer [1]	Sustainable alternative	Score	Explanation
PMMA	Recycled PMMA	15	Very efficient recycling, lower price, TRL 9, commercially scaled in relevant size.
	Bio-based PMMA	11	Alternative is biobased, limited insights into price, however, lower price not guaranteed, production scale varies by supplier.
Textile fibers	Cellulose acetate	13	Alternative is biobased, similar price, commercially scaled in relevant size.
	PEF	11	Alternative is biobased, has a higher price, is still in early commercialization stages but emerging to be industrially scaled.
Resin in paints/varnishes	Bio-based MPA	13	Alternative is biobased, offtake agreements indicate acceptable market price/similar price, is beyond lab and pilot stage as industrial validation has happened and commercial scale-up is planned in 2026.
	PLA	11	Alternative is biobased, similar price, most technologies remain at pilot or early demonstration level.

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1) This list highlights the polymers that represent the largest share of material content within the selected product groups.

Ranking of sustainable polymers resulted in a new selection of those alternatives scoring a 9 or higher

The highest scoring sustainable alternatives based on reduction potential of carbon footprint [CO2eq/ton], cost of alternative compared to fossil polymer [€/ton] and technical maturity (TRL)

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Ranking of sustainable polymer alternatives* (high to low)	Weighted Score
Recycled PVC, Recycled PMMA, Recycled PA	15
Recycled ABS, Cellulose acetate, Bio-based MPA, Starch film, Natural latex/rubber	13
PHA, PLA (as substitute for ABS/ASA/SAN), Bio-based EVA, PEF (as substitute for PET)	12
Recycled PET, Bio-based PA, Bio-based PMMA, PLA (as substitute for EVA), PEF (for textiles)	11
Bio-based PE-HD, Bio-based PE-LD, PLA and PHA (as substitute for PS), Mycelium (as substitute for PS and for PUR), PLA (as substitute for PP), Recycled PU foam	10
Recycled PE-HD, Bio-based PP, TPU, Biobased ABS, Biobased PAU, Biobased ABS, Bio-based PUR	9

* Sustainable polymer that was part of the study but scored under 9: Recycled PE-LD

The ranking of the 9 product groups by production volume and the sustainable polymers is combined and results in four product group-sustainable polymer couples

The product group-polymer couples that are selected due to a high production volume combined with a high scoring sustainable alternative for their current fossil polymer content.

Industry	Product group	Volume [Mt]	Fossil polymer	Sustainable alternative	Explanation
Packaging	**Plastic films, sheets and foils**	4,8	PE-LD	**Starch**	Starch is commercially mature, cost competitive for short life packaging, and significantly reduces emissions due to its bio-based origin.
			PP	**PLA**	Due to PLA's bio-based origin it suits circular economy goals. Its TRL and growing production capacity make it a viable option for short- to medium-term implementation, though cost competitiveness improves with scale.
	Plastic bottles and containers	1,2	PET	**PEF**	PEF is a promising substitute as it offers higher technology readiness, CO_2 reduction due to its bio-based origin, and improved material performance such as better barrier properties. While current costs can be higher than PET, economies of scale and growing production capacity are expected to make PEF increasingly competitive.
Textiles	**Textiles and apparel**	3,7	PET	**PEF**	
			PA	**Recycled PA (rPA)**	rPA significantly reduces CO_2 emissions by avoiding fossil-based feedstock and utilizing post-consumer or industrial waste. Its technology readiness is high, as mechanical and chemical recycling processes for PA are already commercially implemented in textile applications. Cost for consumers is increasingly competitive as recycling infrastructure scales, making r-PA a viable and sustainable alternative without major performance compromises.
Chemicals	**Paints and varnishes based on polymers**	1,5	EVA	**PLA**	PLA is a potential substitute for vinyl-based binders in paints and varnishes. Although its technology readiness level is still relatively low and it is currently used mainly in niche applications, costs are expected to become more competitive as production scales and demand for bio-based polymers increases. Moreover, biobased alternatives for paint formulations are widely researched because of their promising potential. For this reason, this study uses the EVA/PLA comparison as an indicative benchmark for bio-based substitutes more broadly.
			PA	**Bio-MPA**	Bio-PMA is also bio-based. Its technology readiness is moderate, with pilot-scale applications already demonstrated, and costs are expected to decrease as production scales
Houseware, leisure and sports	**Furniture**	1,5	PUR (PU foam)	**Recycled PU foam**	Recycled PU foam is a alternative to the high volume of PU foam in furniture because it reduces CO_2 emissions by avoiding fossil-based feedstock and minimizing waste through circular use. Its technology readiness is low to moderate, with pilot-scale processes available.

Why certain high-scoring product groups were not selected for further research

Other High-scoring product groups that are not included including explanation

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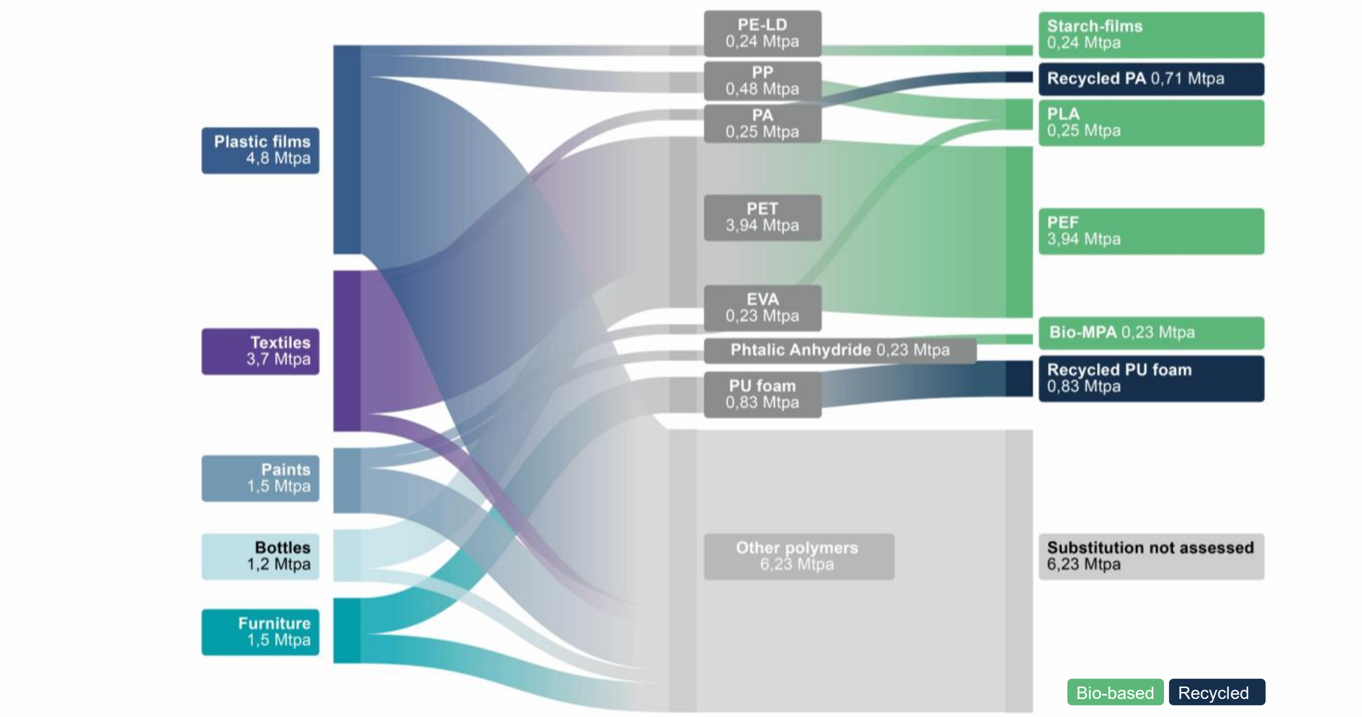
Industry	Product group	Volume [Mt]	Fossil polymer	Sustainable alternative	Explanation
Automotive	**Tires**	2,0 Mtons	Latex, PA	**Natural rubber**	Additional product regulation here would have limited additive effect. Although tires are a priority product group under the ESPR (Ecodesign for Sustainable Products Regulation), researching them further within this study is not impactful for several reasons. Firstly, is regulatory saturation, tire materials are regulated under other EU legislation (e.g., Tire Labelling Regulation (EU) 2020/740). Additionally, scaling natural rubber production poses sustainability challenges (e.g. deforestation). Focus on the fibers in tires is possible, but that volume is found to be relatively low to other fossil content in product groups within this study. Further focus on tires does not significantly contribute to demand driven sustainable carbon use, nor is it aligned with the study's ambition for impactful regulatory intervention.
Building and construction	**PVC pipes and hoses**	1,0 Mtons	PVC	**Recycled PVC**	Recycled PVC is already widely used in the construction sector. Introducing new regulatory requirements would not significantly increase sustainable carbon uptake because the market is already performing well.
Packaging	**Plastic bottles and containers**	1,2 Mtons	PET	**Recycled PET**	Mechanical rPET faces quality limitations and concerns raised during this research about potential microplastic release and related health risks in consumer-contact applications. Chemical recycling could address purity issues but is more energy intensive, resulting in a lower footprint and limited relevance for this study. Therefore, PET recycling routes were excluded from further analysis.
Electrical and electronics	**Small household appliances**	1,2 Mtons	PP	**Recycled PP; ABS, PA**	Producers are already shifting toward lighter, more sustainable designs, including the use of recycled plastics. These appliances contain multiple polymers, electronics, metals and flame-retardant parts, which limits substitution due to performance and safety requirements. The product group also includes many subtypes (e.g., mixers, irons, vacuums, hairdryers), diluting the regulatory impact of targeting the category as a whole. Overall, the diversity and ongoing voluntary transitions reduce the effectiveness of further regulation to stimulate sustainable carbon demand.

F Appendix: Economic analysis

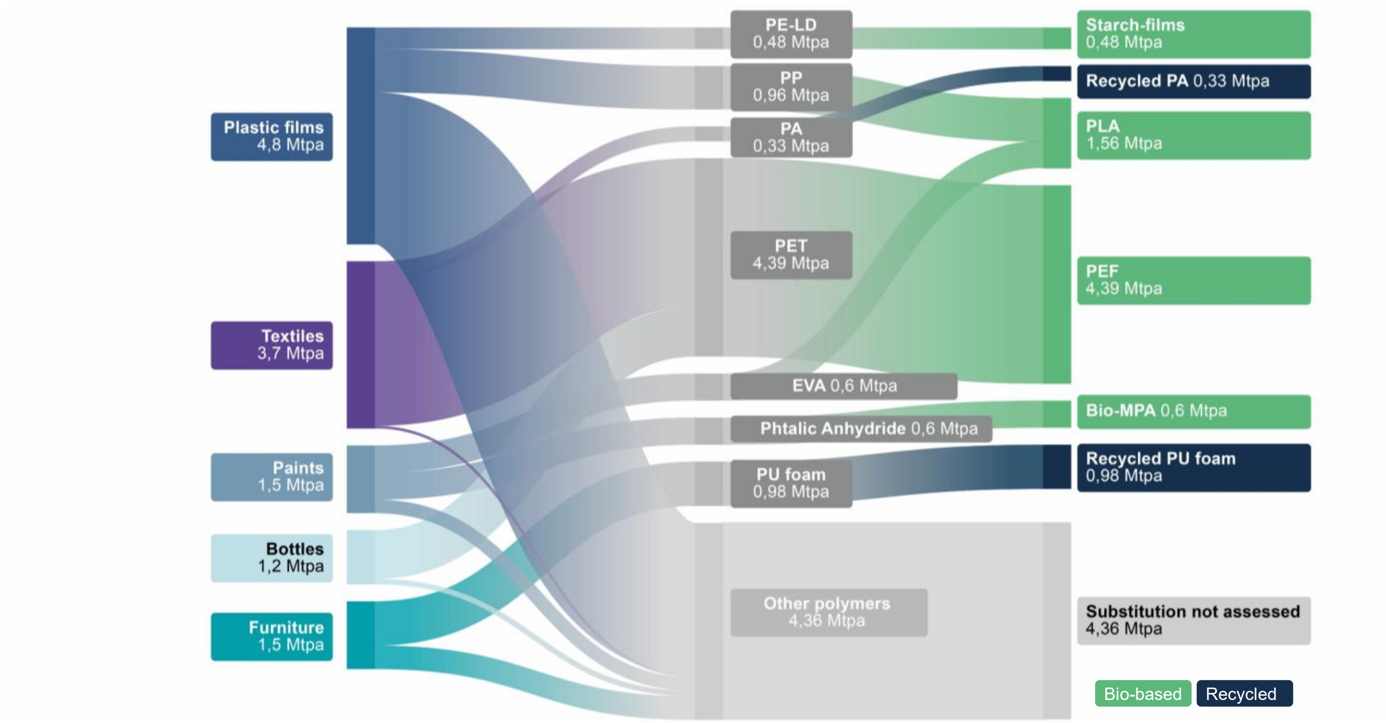
In the low case, the theoretical maximum demand is 6.2 Mton per annum.

Low case – demand creation



In the high case, the theoretical maximum demand is 8.4 Mton per annum.

High case – demand creation



Market Creation Assessment assumptions and sources

Substitution potential assumptions, based on desk research and expert interviews

Industry	Product group	Fossil polymer	Sustainable alternative	Substitution potential (low/mid/high)	Underlying source/assumption
Packaging	Plastic films, sheets and foils	PE-LD	Starch-film	10 / 15 / 20 %	Roughly 25% of category PP (bubble chart), of which ~60% can be substituted due to PLA characteristics based on expert knowledge.
		PP	PLA	5 / 7.5 / 10 %	Roughly 25% of category PE-LD (bubble chart), of which ~30% can be substituted because starch is not water resistant, based on expert knowledge.
	Plastic bottles and containers	PET	PEF	75 / 83 / 90 %	0.7 Mtpa PP demand for bottle caps, 3.1 Mtpa PET demand for bottles --> between 75 and 90% PET. hdpe-pp-market-in-europe.pdf PET-Market-in-Europe-State-of-Play-2022-Data-V3.pdf
Textiles	Textiles and apparel	PET	PEF	82 / 85 / 90 %	Materials Market Report, Textile Exchange, Sept. 2024
		PA	Recycled PA	7 / 8 / 9 %	Materials Market Report, Textile Exchange, Sept. 2024
Chemicals	Paints/varnishes based on polymers	Phthalic anhydride[1]	Bio-MPA[2]	15 / 30 / 40 %	De bestanddelen van verf, Nederlandse Bouwdocumentatie
		EVA[3]	PLA	15 / 30 / 40 %	De bestanddelen van verf, Nederlandse Bouwdocumentatie
Houseware, leisure & sports	Furniture	PU foam	Recycled PU foam	55 / 60 / 65 %	Europe PU flex foam output falls 2.7pc in 2024 | Latest Market News

1) Phthalic anhydride is an alkyd; 2) Bio-based maleic phthalic anhydride; 3) Ethylene vinyl acetate is a vinyl

Feedstock requirements assumptions and sources

Feedstock assumptions, based on desk research and expert interviews

Sustainable alternative	Feedstock	Required (low/mid/high)	Underlying source/assumption	Global feedstock availability	Underlying source/assumption	Availability development
Starch-films	Starch	0.50 / 0.75 / 0.80 kg / kg alternative	Combination of Poly(lactic) Acid and Starch for Biodegradable Food Packaging - PMC	156.15 Mtpa	starch-world-market.pdf	Expected increase due to efficiencies and improved connectedness of supply chain. Weather and climate effects are a risk. Starch Market Growth Analysis - Size and Forecast 2024-2028 | Technavio
PLA	Starch	1.44 / 1.60 / 1.76 kg / kg alternative	Whitepaper-on-the-bio-based-sugarcane-feedstock-of-Luminy-PLA.pdf			
PEF	Sugar	1.00 / 1.20 / 1.30 kg / kg alternative	LCA Avantium, checked will molar balance, and Eerhart et al. 2012	211.35 Mtpa	Industrial Sugar Market worth $59.1 billion by 2028	Sugar availability is expected to increase with consumption in the food sector expected to come down, and new recycled and waste stream sugar becoming available.
	Glycerol	0.34 / 0.34 / 0.34 kg / kg alternative	LCA Avantium, checked with molar balance, and Eerhart et al. 2012	15 Mtpa	5.6 BN market value, 720-1050 $/ton	Expected increase Glycerin Market Size, Growth & Outlook, Trends Report 2030
Recycled PA	Waste PA	1.00 / 1.05 / 1.10 kg / kg alternative	Typical recycling losses of 0-10% between waste and recycled products.	3 Mtpa	1.5% of global plastic use, assumed 50% recycling potential by 2030	Recycling rate is expected to increase
Bio-MPA[2]	Furfural	1.30 / 1.40 / 1.50 kg / kg alternative	2 mol furfural per mol bio-MPA + production losses (80-90% yield)	1.71 Mtpa	China produced 1.2 Mtpa, 70% of global capacity	Nascent market, many consumers will opt for inhouse production based on sugar.
Recycled PU foam	Waste PU	1.00 / 1.05 / 1.10 kg / kg alternative	Typical recycling losses of 0-10% between waste and recycled products.	2.58 Mtpa	A systematic review on the recycling of polyurethane products from offshore applications - ScienceDirect	Recycling rate is expected to increase

1) Phthalic anhydride is an alkyd; 2) Bio-based maleic phthalic anhydride; 3) Ethylene vinyl acetate is a vinyl

Plant capacity assumptions and sources

Plant capacity assumptions, based on desk research and expert interviews.

Industry	Product group	Fossil polymer	Sustainable alternative	Reasonable production capacity	Underlying source/assumption
Packaging	Plastic films, sheets and foils	PE-LD	Starch bio-polymer	10 ktpa	Based on interview with Tony Starch, start at 10 ktpa and then scalable with 3-5 ktpa steps.
		PP	PLA	40 ktpa	Plant capacities possible form 1-100 kton, even plants emerging from 160 kton/year. 40 kton selected as small-scale additional capacity.
	Plastic bottles and containers	PET	PEF	5 ktpa	Plant capacity of first-of-a-kind plant of Avantium in Delfzijl, Netherlands.
Textiles	Textiles and apparel	PA	Recycled PA	7 ktpa	Existing market, with planned capacities up to 20 ktpa. The assumption of 7 ktpa is again done as small-scale additional capacity.
Chemicals	Paints/varnishes based on polymers	Phthalic anhydride1)	Bio-MPA2)	6 ktpa	Theoretical plant sizes 5-7 ktpa bases on research
		EVA3)	PLA	40 ktpa	Plant capacities possible form 1-100 kton, even plants emerging from 160 kton/year. 40 kton selected as small-scale additional capacity.
Houseware, leisure & sports	Furniture	PU foam	Recycled PU foam	6 ktpa	New plant in France processes 750.000 mattresses a year, at an average weight of 20 kg and an 80% recycling efficiency, 6 ktpa.

1) Phthalic anhydride is an alkyd; 2) Bio-based maleic phthalic anhydride; 3) Ethylene vinyl acetate is a vinyl

Cost impact assumptions

Cost impact assumptions, based on desk research and expert interviews.

Industry	Product group	Fossil polymer	Costs (€/ton)	Source	Sustainable alternative	Costs (€/ton)	Source
Packaging	Plastic films, sheets and foils	PE-LD	1110 - 1300	ICIS Europe LDPE film prices (NWE, 2024)	Starch bio-polymer	1840 - 2760	Nova Institute (2024); Avérous et al., Prog. Polym. Science Direct
		PP	995 - 1170	ICIS Polypropylene Europe (NWE, 2024)	PLA	1745 - 2785	Industry Today; ICIS biopolymers Europe (2024)
	Plastic bottles and containers	PET	690 - 1640	ICIS PET Europe price assessments (2024)	PEF	3330 - 4090	Avantium; CE Delft market estimates (2024)
Textiles	Textiles and apparel	PA	1398 - 2098	ICIS Polyamide 6 Europe; IMARC Germany PA6 (2024)	Recycled PA	2170 - 3250	PIE recycled PA Europe (2024–25)
Chemicals	Paints/varnishes based on polymers	Phthalic anhydride	1200 - 2000	ICIS Phthalic Anhydride Europe (2024)	Bio-MPA	1480 - 1950	MarketsandMarkets (2024); procurement benchmarks
		EVA	1600 - 2400	ICIS EVA Europe price assessments (2024)	PLA	1745 - 2785	Industry Today; ICIS biopolymers Europe (2024)
Houseware, leisure & sports	Furniture	PU foam	1600 - 1900	BPF PU feedstock-based system cost (EU, 2024)	Recycled PU foam	1400 - 2100	EUROPUR recycled PU foam Europe (2024)

Cost impact assumptions

Cost impact assumptions , based on desk research and expert interviews.

Industry	Product group	Fossil polymer	Sustainable alternative	Product	Polymer content (gram/unit)	Source/Assumption	Substitution factor	Source/Assumption
Packaging	Plastic films, sheets and foils	PE-LD	Starch bio-polymer	Textiles poly mailer	9.9	Area x thickness x density (25.5x33 cm) x (2 layers) x 0.92 g/cm2)	1.31	Comparison two packaged. LD-PE package 10 gram, starch bases 13 gram.
		PP	PLA	PP-tape	143	PP Hot Melt Tape Transparent, 48 mm x 66 m. 36 rolls. | Kortpack B.V.	1.1	PLA is stronger, but more brittle. More material needed.
	Plastic bottles and containers	PET	PEF	Soda bottle	22	1 Liter Clear PET Plastic Bottle & Screw Cap - Ampulla Ltd (10% of weight is cap)	0.8	PEF world congress
Textiles	Textiles and apparel	PET	PEF	Fleeces	212	Based on 450g mens amazon essential 1/4 zip in medium, 44% polymer, 56% cotton	0.9	Bottles confirmed 0.8, requirements for fleece not certain, +10% to be conservative.
		PA	Recycled PA	Sports shirt	126	Based of web shop. 87% of shirt is Nylon(PA) . Total shirt approximate 145 grams, of which 126 grams of nylon.	1.1	Recycled material has worse characteristics than virgin alternative
Chemicals	Paints/varnishes based on polymers	Phthalic anhydride	Bio-MPA	Wall paint	300	For a 1L can of perfection Wit paint, density is 1.5kg/L with acrylic binder at 20% = 300g per liter	0.9	Expert interview. For some paints 0.5 would be sufficient.
		EVA	PLA	Paint primer	450	1.5 kg/L × 0.30(%) = 0.45 kg PVAc/VAE binder per liter	1	Expert interview. Stability might be an issue.
Houseware, leisure & sports	Furniture	PU foam	Recycled PU foam	2-person sofa	11000	55 kg total sofa × 0.20(%) = 11 kg PU foam per unit	1.1	Recycled material has worse characteristics than virgin alternative

Market size assumptions

Market size assumptions , based on desk research and expert interviews.

Industry	Product group	Fossil polymer	Sustainable alternative	Product	Market size (million units / year)	Source/Assumption
Packaging	Plastic films, sheets and foils	PE-LD	Starch bio-polymer	Textiles poly mailer	9	EU plans 2 euro fee for low-value parcels in setback for Shein, Temu | Reuters 4.6 bn clothing packages from China, which is 50% of all apparel e-commerce Where do our clothes come from? - Products Eurostat News - Eurostat
		PP	PLA	PP-tape	210	Cepi-Preliminary-Statistics-report-2023.pdf 30 mt board, 0.6 kg per box, 40% requires tape, 1 m tape per box. 66 m per roll, 70% of tape rolls is PP-tape.
	Plastic bottles and containers	PET	PEF	Soda bottle	75,000	https://www.euwid-recycling.com/news/business/pet-recycling-making-progress-in-europe-120424/
Textiles	Textiles and apparel	PET	PEF	Fleeces	20	EU Market sell €2.25bn fleece clothing per year with 20% sub-segment of 1/4 zip fleece. 0.5bn / €24.99 = 20.008.003
		PA	Recycled PA	Sports shirt	400	450m EU citizens, 45% regularly sport (2 shirts per year) and 10% are occasional sporters (0.2 shirts per year) Rounded down.
Chemicals	Paints/varnishes based on polymers	Phthalic anhydride	Bio-MPA	Wall paint	445	Total European paint & coating market = €30-35bn, architectural coatings accounts for 45.86% = 14-16bn. Assume EU = 70% of of Europe = €10-11bn (10.5bn midpoint). Wall paint is 70% of architectural paint = 7.35bn/year / 17.4 €/L = 442.4 million L/yr
		EVA	PLA	Paint primer	100	Total European paint & coating market = €30-35bn, architectural coatings accounts for 45.86% = 14-16bn. Assume EU = 70% of of Europe = €10-11bn (10.5bn midpoint). Pain primer is 15% of (10.5bn) architectural paint = 1.58bn/year @ 16,40 €/L = 96.34million L/yr
Houseware, leisure & sports	Furniture	PU foam	Recycled PU foam	2-person sofa	7.27	202m (EU households) x 0.9 (most EU households own a sofa) x 0.1 (10 year sofa lifespan) x 0.40 (2-seater share) = 7.27 million 2-person sofas per year in EU

F Appendix: Environmental Impact Analysis

Data sources for environmental impact analysis of fossil polymers

Overview of data availability and analysis per comparison

Fossil polymer	Data source	Comments
PE-LD	EcoInvent	Polyethylene, low density, granulate {RER}| polyethylene production, low density, granulate | Cut-off, U
PP	EcoInvent	Polypropylene, granulate {RER}| polypropylene production, granulate | Cut-off, U
PET	External LCA from Avantium	This LCA uses PET granulates LCA data from EcoInvent.
PA	EcoInvent	Nylon 6-6 {RER}| nylon 6-6 production | Cut-off, U
Phthalic anhydride	EcoInvent	Phthalic anhydride {RER}| phthalic anhydride production, o-xylene oxidation | Cut-off, U
EVA	EcoInvent	Ethylene vinyl acetate copolymer {RER}| ethylene vinyl acetate copolymer production | Cut-off, U
PU foam	Ecoinvent	Polyurethane, flexible foam {RER}| polyurethane production, flexible foam, TDI-based, high density | Cut-off, U
General/other	n/a	Andreasi Bassi S., Biganzoli F., Ferrara N., Amadei A., Valente A., Sala S., Ardente F., Updated characterization and normalization factors for the Environmental Footprint 3.1 method. Publications Office of the European Union, Luxembourg, 2023, doi:10.2760/798894, JRC130796.

Sources: Ecoinvent

Data sources for environmental impact analysis of sustainable alternatives

Overview of data availability and analysis per comparison

Sustainable alternative	Data source	Comments
Starch	LCA of starch products for the European starch industry association: Summary report Starch Europe	Starch can be made from wheat, maize and potatoes. This LCA coverts the production of modified starch out of corn starch. Biogenic carbon uptake calculated
PLA	TotalEnergie and Corbion	Produced from sugarcane. 3.10 EcoInvent Cut-off)
PEF	External LCA	LCA from Avantium. PEF production compared with the European production of PET Same procedure EF3.1. However different weighting, adjusted weighting to latest update.
Recycled PA	Ecoinvent	Compare with recycled PET from EcoInvent (Polyethylene terephthalate, granulate, amorphous, recycled {US}| polyethylene terephthalate production, granulate, amorphous, recycled | Cut-off, U)
Bio-MPA	External LCA	LCA from Relement
Recycled PU foam	Recycling Flexible Polyurethane Foam via Chemical Recovery Versus Incineration for Energy: A Comparison of Environmental and Economic Impacts (2019), Pyrolyse Recycling Initiatief voor Matrassen, Koninklijke CBM, Branchevereniging voor Interieurbouw en Meubelindustrie	Mainly use of publicly available sources

Sources: Ecoinvent

F

Appendix: Policy Analysis

Appendix I EU legislation: four types of instruments

“Hard” legislation is considered most influential to achieve short term direct impact on sustainable carbon for product groups

EU policy instruments

1. Policy frameworks & strategies
Policy frameworks and strategies are structured guidelines and action plans that set principles, objectives, and methods for achieving specific goals. In principal, these frameworks and strategies guide legislative and funding priorities.

2. “Hard” legislation
Hard legislation refers to legally binding rules, regulations, or instruments that are enforceable by courts or other legal authorities. These include statutes, treaties, and formal regulations.

3. “Soft” legislation
Soft legislation consists of non-binding guidelines, principles, codes of conduct, or recommendations that influence behavior but lack legal enforceability.

4. Economic instruments
Economic instruments are policy tools that use financial incentives or disincentives to influence behavior and achieve policy objectives.

2a. Regulation
A "regulation" is a binding legislative act. It must be applied in its entirety across the EU. This means that the applied is applied in all EU-countries.

2b. Delegated act
A “delegated act” allows the Commission to amend or supplement non-essential parts of legislation.

2c. Implementing act
An “implementing act” aims to create uniform conditions for the implementation of the legislative act in question, if and when this is necessary.

2d. Directive
A "directive" is a legislative act that sets out a goal that EU-countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals.

2e. Decision
A "decision" is binding on those to whom it is addressed (e.g. an EU country or an individual company) and is directly applicable.

Focus on hard legislation

- The goal of this project is to review direct impact opportunities on new sustainable carbon legislation across the EU. This means establishing binding rules that set measurable targets for sustainable carbon use in product design, supply chains, and recycling for key product groups.
- To achieve uniform implementation, the focus is on opportunities for hard legislation with immediate EU-wide effect such as regulations, delegated acts, implementing acts, and decisions.
- Directives, which requires Member States to transpose it in national laws, have a certain degree of flexibility and are therefore considered less suitable for product groups because they do not guarantee consistent application across all Member States.

Overview of EU legislation: multiple legislative instruments with impact on sustainable carbon

Opportunities and obstacles appear in regulations and technical standards and norms

EU instrument	Subcategory	Legislative title	Publc. date	Opportunity	Obstacle
Policy frameworks & strategies	Strategic policy framework	Green Deal	2019		
	Strategies & action plans	Circular Economy Action Plan (CEAP)	2020		
		EU Sustainable Finance Strategy	2021		
		EU Bioeconomy Strategy	2025		
		EU Plastics Strategy	2018		
		EU Policy Framework on Bio-based, Biodegradable and Compostable Plastics	2022		
"Hard" legislation	Directives	Single-Use Plastics Directive (SUPD)	2019		
		Waste Framework Directive (WFD)	2008		X
		Corporate Sustainability Reporting Directive (CSRD)	2022		
		Corporate Sustainability Due Diligence Directive (CSDDD)	2024		
	Regulations	Registration, Evaluation Authorisation and Restriction of Chemicals (REACH)	2006		X
		Ecodesign for Sustainable Products Regulation (ESPR)	2024	X	
		Packaging and Packaging Waste Regulation (PPWR)	2025	X	
		Waste Shipment Regulation (WSR)	2024		X
		EU Taxonomy Regulation	2020		
"Soft" legislation	Technical standards and norms	Physical property norms for health, safety and performance	Various		(X)
Economic instruments	Market based mechanism	EU Emissions Trading System (EU ETS)	2003		

Sustainability versus standards

- The current EU legal framework creates opportunities for EU-wide impact on product group sustainability targets through regulations that are legally enforceable.
- However, strict product-specific requirements often take precedence over sustainability goals.
- For example, using recycled plastic polymers in food packaging could significantly support EU-wide targets. However, food packaging has to be safe and should not contain unwanted chemicals.

- Opportunities: PPWR and ESPR
- Obstacles: WFD, REACH, WSR, and physical property norms and standards

Reports and other data sources for policy analysis

Overview of sources

#	Name	Data source
1	The Circular Economy for Plastics	Circular_Economy_report_Digital_light_FINAL.pdf
2	Report presenting a Material Flow Analysis (MFA) model developed for the EU plastic value chain.	JRC Publications Repository - Plastics materials flows in the EU-27 and their environmental impacts
3	Plastics – the fast Facts 2023 by Plastics Europe	Plasticsthefastfacts2023-1.pdf
4	The Plastics Transition by Plastics Europe	The Plastics Transition • Plastics Europe
5	Dataset of publications by plastics recyclers Europe	Publications - Plastics Recyclers Europe
6	HDPE & PP MARKET in Europe – state of play by plastics recyclers Europe	HDPE & PP Market in Europe
7	Textiles Circularity Metrics Lab by European Environmental Agency	Textiles | Circularity Metrics Lab
8	PET market in Europe, state of play by I.C.I.S.	PET Market in Europe
9	New bio-based polymer PEF shows low CO2 footprint (Peer-reviewed LCA) by Renewable Carbon News	New bio-based polymer PEF shows low CO2 footprint
10	Plastics – the Facts 2022 by Plastics Europe	Plastics Fact Sheet 2022
11	Crunch time for textile brands - ESPR working plan released by Trimco Group	April 19, 2025 - new Updates to ESPR for textile & footwear brands
12	Strategic Recommendations for a Resilient and Circular Plastic Value Chain in Europe	Strategic-Recommendations-for-a-Resilient-and-Circular-Plastics-Value-Chain-in-Europe-1.pdf
13	Recycling Industry urgently calls for the adoption of EU-wide end-of-waste criteria for plastic wastes	Joint Association Statement - call for EoW criteria for plastics - FINAL.pdf
14	Biotech Act 2	Biotech Act 2
15	Circular Economy Act	Circular Economy Act

Sources: Ecoinvent