



# ESCIB – Environmental Sustainability & Circularity Assessment for Industrial Bio-based Systems

## Recommendations of the first project period

January 2026

### HIGHLIGHTS

- Industrial bio-based systems (IBBS) **are clearly an important solution, among others, to reduce the use of fossil resources**. The development of new IBBS is related to many challenges and need to be supported by different means. This includes their assessment related to environmental sustainability and circularity.
- Most IBBS in the EU rely on primary wood-based biomass and agricultural biomass, while the **use of residues and wastes as feedstock remains limited**, despite its large and untapped potential for circularity and for reducing import dependence.
- **Environmental performance of IBBS is often better** than fossil alternatives for climate and fossil resource use, but trade-offs for land use, eutrophication, acidification and water use are common and must be managed. This highly depends on the origin of the used biomass.
- **Circular performance is strongly driven by end-of-life (EoL) systems**: design for reuse and recycling and high-quality waste management generally outperform energy recovery and disposal.
- Priority investments should target IBBS that:
  - **use residues, by-products and biogenic wastes**;
  - **demonstrate robust net benefits** across multiple environmental impact categories;
  - **embed circular design** (repair, reuse, cascading use, and recycling) and high-quality end of life options.
- **ESCIB suggests a harmonized classification framework** for IBBS, which is based on systemization by life cycle elements and enables consistent and comparable evaluations of environmental sustainability and circularity across IBBSs.



## Context: why environmental and circular performance of IBBS matters now

The **European Green Deal**, the **Circular Economy Action Plan**, the updated **EU Bioeconomy Strategy** and related initiatives all position the bio-based economy as a key lever for achieving climate neutrality, resource efficiency and reduced pollution.

**Industrial bio-based systems**, which transform biomass into non-food, non-feed materials and products such as bioplastics, biochemicals and wood-based materials, **are expected to contribute significantly to these objectives**.

However, the simple fact that a product is bio-based does not guarantee that it is environmentally sustainable or circular. Many existing industrial bio-based systems rely on primary agricultural and forestry biomass that can place additional pressure on land, biodiversity, soil and water, and may compete with food, feed and other uses or ecosystem services. Life-cycle assessments frequently show improved performance for climate change and fossil resource depletion when compared with fossil-based counterparts, but the same studies often reveal more mixed outcomes for

eutrophication, acidification, water use or land use, particularly in crop-based systems. **These trade-offs between bio-based products and their counterparts need to be assessed in order to be able to “judge” the sustainability of products.**

Furthermore, circularity outcomes depend as much on design, use and end-of-life management as on the origin of the carbon in the product.

At the same time, policy instruments, funding programmes and market mechanisms increasingly reward bio-based content without systematically incorporating harmonised, multi-impact criteria for environmental and circular performance. This creates a risk that investments will flow to systems that are bio-based in name but not necessarily aligned with broader EU sustainability objectives.

**Clear, policy-relevant evidence and operational benchmarks are therefore needed to distinguish between bio-based systems that genuinely support the Green Deal and those that do not.**

## Addressing the challenge: methodologies from ESCIB

The ESCIB project addresses this challenge by **developing robust methodologies and practical tools to assess the environmental sustainability and circularity of industrial bio-based systems**, and by translating this evidence into guidance for policymakers and funding bodies.

The current paper highlights key recommendations of ESCIB at its **interim stage as of January 2026**. The research in the project continues until end of 2027 and main results are upcoming in this period.

Our work provides the empirical and conceptual foundations for this work. ESCIB maps existing high technology readiness level industrial bio-based systems across the EU-27. It compiles data on agricultural and forestry production, biomass availability, industrial capacities and biogenic waste generation and treatment, focusing explicitly on material-oriented value chains rather than food, feed or purely energetic uses. This mapping shows where biomass is produced, how it is currently mobilised, and where significant waste and residue streams remain underused as material feedstock.

The report “**Classification and Systemization of the High TRL Industrial Biobased Systems**” and paper by Khan et al. (2026) develops a systemisation of bio-based systems, offering a classification that distinguishes between primary dedicated biomass, primary residues, secondary residues, primary waste and secondary waste. This classification is linked to processing routes such as mechanical, biochemical and thermochemical conversion, as well as to broad product categories including plastics, chemicals and wood-based products. The systemisation allows different value chains to be

compared on a comparable basis in terms of feedstock origin and position in the value chain.

The report “**Review and Meta-analysis of Environmental and Circular Performances**” reviews and synthesises existing evidence on the environmental and circular performance of selected high-TRL industrial bio-based systems, with a focus on bioplastics, biochemicals and wood-based products. The analysis draws on life-cycle assessment and circularity studies to identify common patterns and trade-offs. It shows that many systems reduce greenhouse gas emissions and fossil resource use compared with fossil-based alternatives, but it also reveals that trade-offs and uncertainties are frequent, and that results depend heavily on feedstock choice, process efficiency and end-of-life scenarios.

The report currently under preparation on “**Benchmarks of best performances**”, is designed to translate these insights into benchmarks for environmental sustainability and circularity. These benchmarks will define performance envelopes and indicative thresholds for key indicators and circularity aspects, providing an operational reference for policymakers, public funders and private investors who wish to target support to the best-performing industrial bio-based systems.

Taken together, the mapping, systemisation, performance review and forthcoming benchmarks form a coherent evidence base that can be used to orient investments towards industrial bio-based systems that are both environmentally sustainable and genuinely circular, and to identify where further research, innovation or governance measures are required.

## Key Recommendations: Targeting investments where they deliver most

### Support IBBS that use residues, by-products and biogenic wastes

One central insight from ESCIB is that many existing industrial bio-based systems rely predominantly on primary agricultural and forestry biomass.

However, the EU already generates large volumes of biogenic waste and residues, including wood waste, paper and cardboard, agro-industrial residues and municipal bio-waste. Much of this material is recovered through either material recycling or energy recovery, yet **the potential to use these streams as feedstock for sustainable and higher-value material applications is far from exhausted**. Due to this potential, policymakers and funding bodies are therefore encouraged **to increase their support** for projects and industrial developments that base their bio-based products on residues, by-products and biogenic waste where this is technically and environmentally appropriate.

This should be reflected in the design and evaluation criteria of research and innovation programmes, in bioeconomy strategies at EU and national level, and in industrial investment plans. Using the classification developed in ESCIB, authorities can distinguish more clearly between dedicated biomass and secondary resources and **track progress towards the use of waste- and residue-based feedstock**.

### Focus investments on systems with demonstrated net environmental benefits across multiple impact categories

The review of environmental performance in ESCIB confirms that industrial bio-based systems usually **reduce greenhouse gas emissions and fossil resource use compared with fossil-based alternatives**. However, it also shows that these gains may be accompanied by **trade-offs** in other environmental

dimensions such as eutrophication, acidification, land occupation or water consumption, particularly when feedstocks are derived from intensive agriculture.

To avoid narrow, carbon-only perspectives, decision makers **should require that environmental assessments used in support of investments in industrial bio-based systems are based on multi-impact life-cycle analysis**. This implies looking simultaneously at climate change, resource and energy use, air and water pollution, land use and other relevant categories.

The upcoming ESCIB benchmarks can be used as a reference point to judge whether a given system's overall performance can be considered favourable, balanced or problematic. **Funding calls and regulatory instruments can then be formulated in ways that reward systems with consistently strong performance** and discourage those that simply shift burdens from one impact category to another.

### Invest in circular design approaches

Circularity in industrial bio-based systems depend on the product properties itself, but also on use patterns and end-of-life management. **Waste management and recycling practices need to be considered in the design of IBBS**.

For bioplastics, for example, climate and resource performances are better if they are compatible with existing recycling systems or if reliable organic recycling routes exist. However, the recycling of bioplastic is often still challenging, and improvements need to be supported. Also, the environmental advantages of wood-based products increase when products are long-lived, reused and recycled before being used for energy recovery at the end of their life.

Public support for new bio-based products should therefore be conditional on **clear and credible circularity concepts**, or in case

that circularity cannot be implemented, address the reasons and highlight trade-offs. Project proposals and investment plans should demonstrate how products are designed for reuse, repair and recycling, and how they will fit into real waste management infrastructures.

Where **new waste collection or recycling systems** are needed, these should be investigated and implemented, if possible. **Harmonised labelling and standards** that facilitate sorting, recycling and cascading use will make it easier for municipalities, companies and consumers to manage bio-based products in line with circular economy principles or policies such as the Ecodesign for Sustainable Products Regulation or the digital product passport approach.

### Support data and methods that reduce uncertainty and enable benchmarking

The mapping of IBBS reveals significant **gaps in the data**, either scattered or incomplete data. This can hinder the understanding of existing IBBS and further policy formulation. Therefore, a combined knowledge platform such as the **Knowledge Centre for Bioeconomy** of the European Commission has a significant role. However, the platform needs to be updated **to present and map more biomass flows and related IBBS** to help with faster policy formulation.

The review carried out in ESCIB also highlights significant **diversity in life-cycle assessment methods, system boundaries, allocation rules and circularity indicators** across studies. This diversity can make it difficult for policymakers to compare competing claims and may lead to contradictory messages about the performance of different value chains.

To address this, there is a need to **invest in the development and maintenance of harmonised and openly accessible life-cycle inventory data and assessment methods** for industrial bio-based systems. ESCIB's methodological work and templates can provide a starting point for such harmonisation. Authorities and funding agencies can encourage or require the use of these approaches

in future projects and can support the integration of ESCIB methods and benchmarks into European and international standardisation activities, certification schemes and labelling initiatives. Over time, this will help create a more level playing field and a shared understanding of what constitutes good performance.

### Align bio-based investments with broader EU environmental targets and ecological boundaries

Industrial bio-based systems operate within the biophysical limits of ecosystems. Expansion of material uses of biomass must remain **compatible with sustainable agricultural and forestry practices, biodiversity protection, soil health, water quality and climate adaptation needs**. Ignoring these constraints risks over-exploitation of biomass resources, land-use change, biodiversity losses and social tensions.

Policy frameworks and investment strategies should therefore be **based on regional biomass and waste balances and on spatially explicit information on land use, ecosystems and environmental pressures**. The mapping approaches used in ESCIB can help to identify which regions have sufficient available residues, by-products and waste streams to support additional industrial bio-based capacity, and where further expansion might conflict with other policy objectives. Projects should be asked to demonstrate that their biomass sourcing strategies and growth trajectories are consistent with ecological boundaries and with “do no significant harm” principles.

### Use ESCIB results to refine research and innovation priorities.

ESCIB shows where industrial bio-based systems are already relatively mature, where promising emerging options need further research and innovation, and where methodological gaps hinder sound decision making. Policymakers can use this information to refine future research and innovation priorities, for example by **directing support towards**

**technologies and value chains that have strong potential** but require improved processes, better integration with waste management, or clearer sustainability evidence.

Beyond research and innovation, ESCIB benchmarks and methods can inform market-creation instruments such as green public

procurement, labelling, sustainability criteria in state aid rules and sectoral regulations. Incorporating performance-based criteria aligned with ESCIB into these instruments can help steer demand and investments towards industrial bio-based systems that genuinely advance EU climate, circular economy and environmental objectives.

## References

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## Imprint

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Editors: Dominik Rutz, Chuan Ma, Rainer Janssen, Utku Ege Birgi

Version: 20.02.2026

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Innovative by nature



The ESCIB project has received funding from the European Union's Horizon Europe Framework Programme under grant agreement No.101135071.

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