

Circular Business Models of Biocomposites: Value Creation in an Industrial Ecosystem

Anu Kurvinen and Alexander Matrosov

Faculty of Business and Hospitality Management, LAB University of Applied Sciences, Lappeenranta, Finland

anu.kurvinen@lab.fi

alexander.matrosov@lab.fi

Abstract: Market and regulatory drivers encourage circularity of materials and the development of circular business models. Governments, companies, and consumers aim to reduce carbon footprints and plastic dependency. The use of biocomposites is increasing globally in various industrial applications. Biocomposites are natural fibre-reinforced materials composed of two or more materials. Conventional materials are in some cases replaced with biocomposites. Product development of substitute products and the establishment of suitable manufacturing infrastructure are complex processes. Business models determine how an organization creates value, delivers value, and captures value linked with internal strategies and processes. All these are needed for business model development and innovation. Linear business models are typically based on the use of virgin materials. In circular business models, resources are circulated as long as feasible, thus eliminating waste, and circulating products and materials. Business models are an interplay between regulations, varying market expectations, and market opportunities. Transition from linear business models towards circular business models requires a system-level approach. This incorporates circular design as a holistic starting point for new product development. The circular approach needs to cover both biological and technical material flows. Strategic business choices for circularity are developed for circular value chains. In a circular approach, the product design process is integrated at an early stage, because design and material choices are closely interlinked, and they affect resources, infrastructures, and activities. This research article combines a literature review of circular business models with the case of biocomposites and studies how adopting biocomposites affects business models and value networks. Circular business models in biocomposite value network are further studied via combining the theoretical insights with interviews that were conducted among companies that participated in a two-year research project related to biocomposites.

Keywords: Circular Business Model, Circular Design, Biocomposite, Natural Fibre Biocomposite

1. Introduction

There is increasing demand for solutions that enhance the sustainability of products throughout product lifecycles, taking into consideration manufacturing, use and end-of-life phases of a product. The concept of the Circular Economy was first introduced in 1989 (Pearce and Turner, 1989). They introduced the new idea of a closed-loop concept where fractions of End-of-Life products can be reinserted as raw materials for new production. Further working and promotion of the idea has been done e.g. by Ellen MacArthur Foundation (2013) when opportunities of Circular Economy were highlighted with the idea to keep materials at their highest value in all phases of their lifecycle in a way where natural benefits of material are enhanced and renewable material flows are managed. The idea of designing products that are circular by design forces value network actors to innovate and to cooperate. Material recycling requires reverse logistics networks and collection systems to support the circular economy. It also leads to higher rates of technological development, improved materials, and more profit opportunities for companies in the industry's value network. Market and regulatory drivers encourage circularity of materials and the development of circular business models. According to Krmela et al. (2022), established businesses face comprehensive circular economy issues at corporate level and sectoral level. Business model dynamics is changing through the implementation of circular economy strategies. Implementing selected circular economy strategies requires thus adapting business models or business model elements. (Krmela et al. 2022) The Finnish research project ABiCo studied biobased biocomposite solutions to replace fossil-based primary raw materials and to increase the use of recycled polymers and biobased raw materials in new, demanding applications, in accordance with the principles of the circular economy. In conjunction with technical development, study on sustainability regulations on biocomposites, techno-economical study, and study on circular business models were conducted. This research article presents a case study of circular business models in case of advanced biocomposites.

Research questions were formulated as follows:

- RQ1: Which business model elements can be aligned with the practical realities of circular business models of advanced biocomposites?

- RQ2: Are there barriers limiting the translation of circular design principles into viable business models for advanced biocomposites?
- RQ3: How can value network actors benefit from implementation of circular business models in advanced biocomposites business?

There are the following limitations to this research. The research is a case study conducted in a co-innovation research project. The study of circular business models is limited to the value network level. The detailed end-of-life analysis of different biocomposite compositions and their business models is excluded from this study.

2. Advanced Biocomposites for Improved Sustainability

Composite materials are a wide family of heterogeneous materials composed of two or more phases, with distinct physical properties. They consist of wood fibers embedded in a petrochemical plastic matrix.

Advanced biocomposites combine the advantages of natural and synthetic components to produce desired qualities, including improved mechanical, thermal, and biological performance (Kiratli 2023). Typical applications of biocomposites are in furniture, automotive, everyday products and construction applications such as decking or cladding (Carus and Partanen, 2018). Biocomposites have been available on the market for decades, but their use has been restricted to limited application areas due to their current performance levels and processability. Now, many industrial areas and brand owners around the world are demanding biocomposites with higher performance levels, suitable for high-quality products. According to market research institutions (Grand View Research, Market Research Future 2026) global use of biocomposites is predicted to grow as the use of eco-friendly materials in industrial applications is promoted.

2.1 Circular Design Framework

A circular design framework comprises multiple disciplines that enable business leaders to develop a step-by-step, systematic circularity strategy. These disciplines are design thinking, futures thinking, service design, and behavioral economics. (Raudaskoski 2022). Circular business models concern how businesses create and capture value in the circular economy framework. Circularity of materials becomes fundamental to how the business model is conceived. Ellen MacArthur Foundation (2019) has described circular economy systems as a diagram with the left wing being biological material cycle and the right wing being technical material cycle. Figure 1 illustrates these cycles.

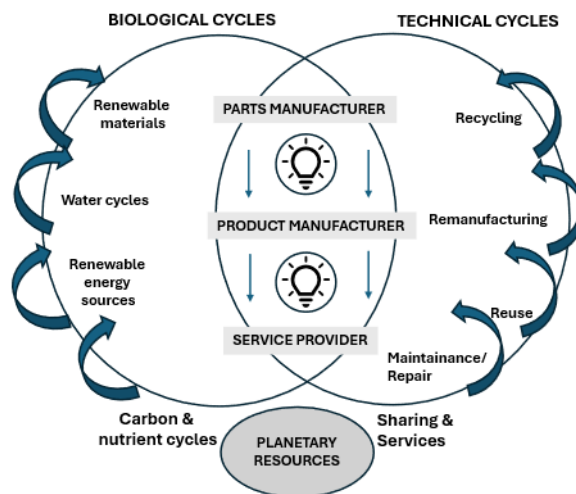


Figure 1: Circular Economy Systems Diagram (adapted from Ellen MacArthur Foundation 2019)

The technical cycle describes how non-renewable materials and products made of these are circulated. Circular business models are based on reuse, repair, and refurbishment, and eventually, when there is no longer a use for the product, its components can be reused. Non-recyclable parts are broken down into constituent materials and will be recycled when possible. Successful circulation of products in either the biological or the technical cycle requires that they have been designed with their eventual circulation in mind. Designing products that stay in the economy and do not end up as waste is the primary target. The left butterfly wing also applies to all companies, even those that use non-renewable materials. Climate regulation, energy sources, and the scarcity

of natural resources affect business and business decisions. EU regulation e.g. *Ecodesign for Sustainable Products Regulation* (ESPR) requires all products to be designed and manufactured according to circularity principles (European Commission 2026).

2.2 Value Network of Advanced Biocomposites

Value chain and processing of advanced biocomposites includes typically following steps: choosing the raw materials, pretreatment, and composite construction. Natural fibers and polymers are some of the raw materials used in biocomposites. For increase of mechanical properties the raw materials are processed using a variety of techniques, like chemical or physical alteration. (Kiratli 2023) Several manufacturing methods were used in the ABiCo project - extrusion, 3D printing and injection molding were tested.

2.3 Circular Business Models – Value Creation with Circularity

New approaches and solutions require new business models that support circularity. A business model describes how an organization functions. (Massa et al., 2016). It presents the “architecture of the value creation, delivery, and capture mechanisms”. Business model is an abstract concept, describing the logic of how the company does business and creates value, what its value proposition is, for whom it creates value and why it is profitable. To capture the value created by innovation, companies need to understand customer needs and technological development opportunities. (Teece, 2010) Main dimensions in business models, as categorized by Osterwalder and Pigneur (2009) are: value proposition - products and services, value delivery - target customers and value delivery processes, value creation - partners, stakeholders, and value creation processes, value capture - revenues and costs. Business models that change dynamically support transition to sustainability (Krmela et al.2022). Business models relate to business ecosystems. Understanding the customer and target industry value network needs not only in the short term but also in the long term, opens new avenues for circular innovation. Adding circularity conditions to the business model thus describes how an organization minimizes the ecological impact of its actions. Breuer et al. (2018) studied sustainability-oriented business model development and stated that there is a contextual expansion of company-centric business models from customers to stakeholders, and from monetary to multiple forms of value. Sustainability orientation requires thinking not only in terms of a single business view but also in terms of a network and systems perspective. According to Breurer et al. (2018), sustainable business models experimentation requires shared principles that guide organizations towards sustainability. These principles are named as sustainability-orientation, extended value creation, systemic thinking, and stakeholder integration. Table 1. presents these guiding principles. (Breurer et al. 2018)

Table 1: Requirements for sustainable business model development (Breurer et al. 2018).

Guiding Principles		Process-Related Criteria	
1	Sustainability orientation	1	Reframing business model components
2	Extended value-creation	2	Context-sensitive modelling
3	Systemic thinking	3	Collaborative modelling
4	Stakeholder integration	4	Managing impacts and outcomes

Systemic thinking includes the concept of circular economy, the physical product life cycle, product-service systems, as well as reflecting the outcomes of the applied business model and how well it delivers sustainability value. In creation of sustainability-oriented business models, all traditional business model components need to be viewed with a sustainability perspective e.g. sustainability impact and potential (Breurer et al. 2018). Circular economy strategies are often called as *9R circular economy framework* (Potting et al. 2016) Each circular economy strategy requires applying business model elements differently. 9R strategies aim to keep materials in the production and consumption cycle and at the most optimal possible level. Waste is to be minimized. Recycling of materials as raw material to new industrial process when possible and gaining better yield of raw materials by e.g. use of industrial side streams as raw material in other production processes, are typical approaches supporting circular economy incentives. 9R strategies with circular economy business model features are listed in Table 2. In addition to 9R's, there is a row 'carbon cycle' added to the table to combine biological material cycle with the technical cycle presentation.

Table 2: 9R Circular economy framework (adapted from Potting et al. 2016) and circular economy business models (adapted from Lüdeke-Freund et al. 2019)

CE Strategy	Key Principle	Description	Circular Economy Bms Used
R0	Refuse	Make redundant, abandon use	
R1	Rethink	Intensive use, sharing, multi-functionality	
R2	Reduce	Consume less resources	
R3	Re-use	Use by another customer	Maintain, redistribute, next-life sales
R4	Repair	Repair, maintain	Repair, product life extension
R5	Refurbish	Restore, bring up to date	
R6	Remanufacture	Use parts for same function	Remanufacturing, next-life sales, product life extension, extending product value
R7	Repurpose	Use parts for different function	
R8	Recycle	Process and obtain same or lower quality	Closed-loop production, rematerialization, recycling & waste management
R9	Recover	Incinerate for energy	
CARBON CYCLES	Organic feedstock	Raw materials derived from plants used as inputs to produce energy, fuels, or industrial products	Co-product generation from waste, circular material supplies, side streams, industrial symbiosis

Lüdeke-Freund et al. (2018) studied recycling business model patterns based on the above-mentioned business model dimension. Material supply chains and reverse material cycles are core in circular economy business models. Recycling business models are part of a value network with partners in a circular supply chain. The value proposition is delivered by closing the resource loops and organizing reverse logistics. This way, users, raw material suppliers, and parts manufacturers are connected. End-users also become resource providers by returning used items to resource loops; manufacturers become customers of raw materials; and waste-collecting operators act as suppliers to manufacturers. Recycling business models relate to both biological and technical cycles. The value created by recycling occurs at both the material and product levels and can be considered downcycling or upcycling. Downcycling means converting waste into materials of lower value than the original material. Upcycling refers to converting waste materials into materials or products of higher quality or value (Sung 2015). The value that is created is captured through additional product revenues or cost savings. Summarizing the cornerstones of circular economy business models is done in Figure 2. (Islam et al. 2025)

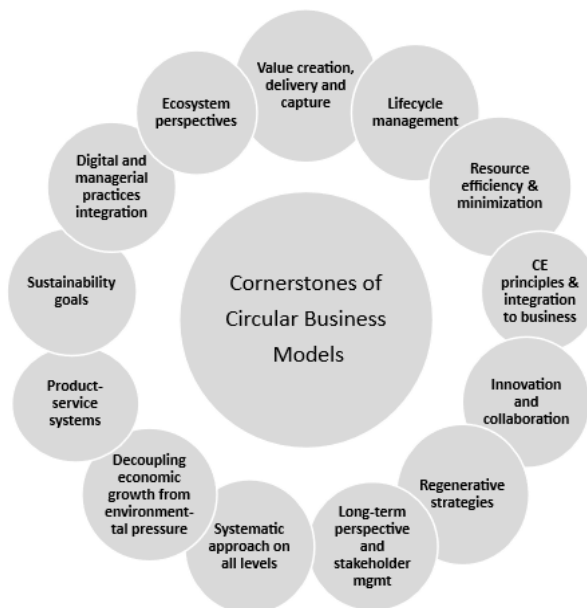


Figure 2: Cornerstones of circular economy business models (adapted from Islam et al. 2025)

2.4 Circular Business Innovation

Circular business encourages innovation, as companies and entire industries seek novel, viable products, services, and solutions that support both biological and technological cycles. In the long run, companies need a long-term vision on sustainability or circularity. Circular innovation becomes more systematic. Based on Image 1, companies and industrial-scale operations require partnering and collaboration with ecosystem partners. New partnerships are needed when new materials and processing methods are adopted and developed. New knowledge is created and must be turned into concrete actions on various parts of the supply chain. Slowing the resource loop can be done by designing products to have a long lifetime and durability, and for extension of product lifetime through maintenance, repair and upgrading (Bocken et al. 2016). Zaei and Klinecicz (2025) classified sub-types of circular product and process innovations in agri-food system. This classification is also valid for advanced biocomposites and is presented in Table 3.

Table 3: Typology of circular product and process innovations (modified from Zaei and Klinecicz, 2025)

Sub-type of Products	Description
Substitute products	More sustainable than existing, known products
Durable products	Products with extended life, longer life span
Recyclable products	Products reducing the need for raw materials, having a "second life" beyond the initially intended use
Material efficiency improvements	New or significantly improved technologies that increase the utilization rate of a material, reduce emissions, cost, or energy usage
Take-back processes (reverse logistics)	Valorization of materials or parts of products
Circular process technologies	Novel and more efficient processing of materials, including the valorization of side streams

3. Methods

Co-innovation project ABiCo forms empirical background for the researched case study. The aim of the project was to develop innovative high-performance biobased biocomposite solutions to replace fossil-based primary raw materials and increase the use of recycled polymers and biobased raw materials in new, demanding applications in accordance with the principles of the circular economy. The advanced biocomposites studied consist of wood fibre and plastics. In the project, advanced biocomposites were created from selected raw materials and additives. Material combinations were tested using standard testing methods and industry-specific requirements (e.g., weathering, UV, fire-retardancy, and material safety testing), as well as processing methodologies (extrusion, 3D printing, foam-forming), and modern AI-aided manufacturing phases. Circular design was the key approach in designing demo compositions and designs, with end-of-life options that support circularity. As a result, material combinations with potential for further industrial-scale development were found. The goal was also to explore potential products that could be designed with the materials tested in the project. Another goal was to scout the legislative environment and business potential for the developed composite materials. The consortium partners - five research institutions and industrial partners closely collaborated throughout the project. Figure 3 describes the project content and stakeholders in the value network.

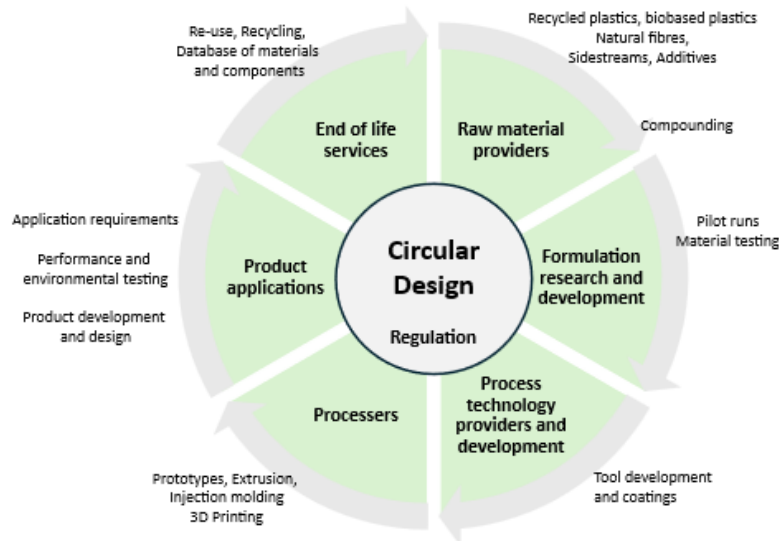


Figure 3: Content of ABiCo project (ABiCo, 2026)

3.1 Research Approach

This research article combines a literature review of circular business models with the case of advanced biocomposites ABiCo project and studies how adopting biocomposites affects business models and value networks. Circular business models in biocomposite value networks are further studied by combining theoretical insights with data from seven company interviews with eight company representatives. All the companies interviewed participated in the two-year ABiCo project. Semi-structured interviews were conducted in May 2025 as one-hour online sessions using Microsoft Teams. Interview data were transcribed, categorized, and analyzed using grounded theory. This method is suitable when the phenomenon under study is new and complex, and when new knowledge is created. The interview questions were sent to the interviewees in advance. Eight topics related to regulatory demands and future business models were discussed with all the companies. The aim was to find out the companies' current and future standpoint towards circular business models in biocomposites sector. Project companies represented the industry value network from different perspectives: material/recycling actor, fibre material actor, construction product manufacturer, biocomposite producer, industrial OEM/device manufacturer, marine industry end user, plastic product manufacturer, circular material producer. The interviewees were from R&D, production, top management, and sales and marketing functions. Industrial end users were from three application areas. Industry partners had their own R&D projects parallel to the public research project, which directed their interest toward the topic.

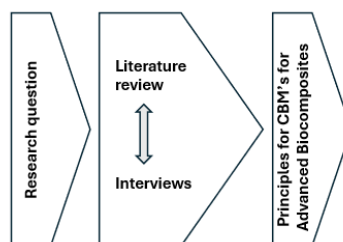


Figure 4: Research approach

As a secondary data source, research documentation from participating research institutes was used. Data collection and analysis took place simultaneously.

3.2 Research Results

When researching new business potential for the whole value network, the following themes were covered: Regulatory viewpoints and role of emerging regulation as driver for market demand, existing customer awareness, existing customer demand, business potential – sustainability vs. cost, recyclability, material loops, market opportunities, value network, and partnering. Table 4 presents a summary of interview results connected

with the value network level. While reviewing circular business, the concept of value networks offers a useful, holistic view of value creation across all network partners in the short and long run.

Table 4: Summary of the interview data

	Raw material supply	Technology providers & Development	Processing/ Manufacturing	Product applications/ Target market	End of life
Reliable supply needed	x		x	x	x
Possible plastic materials to be used in advanced biocomposites.	x	x	x	x	
Biocomposite as an option when another material supply limited	x		x	x	
Direct replacement of existing material in existing process challenging		x	x	x	
Biocomposites as solutions among existing ones		x	x	x	
Possible plastic materials to be used in the manufacturing process	x	x	x		
Material properties. Must work in the production line			x	x	
Demand exists	x		x	x	
Fit company's product selection			x	x	
Value after recycling	x		x		x
Material identification: material knowledge for better recyclability (in order to be utilized to the fullest value)	x				x
Closed-loop recycling systems work.	x		x		x
Raw material waste recycling exists	x		x		x

Circular design and both material cycles – the biological cycle and the technical cycle - presented earlier are both present. During the ABiCo project it was confirmed that there is interest and expectation in the development of selected advanced biocomposite materials for circular materials loops. They also represent potential for further material innovation, technological and process innovation, as well as product and service innovation. Advanced biocomposites are promising materials in circular business models. This is supported by the growing demand, which can be reinforced through the adoption of circular design. Ideologies of circular business models and circular design presented in the literature and use of novel material combinations are challenging due to several reasons. E.g., there are no existing material libraries for designers yet. Circular design could be potentially achieved in large-scale industrial processes that enable their own large-scale material testing, consumption, and development for certain selected end-use applications. There are also end-of-life solutions that can be more easily adapted – raw material flows are easier to control, and material identification is easier. Advanced biocomposites often offer the benefits end users seek (e.g., lightweight structures). The limitation, according to the current study, is that each material and technology solution is tailored for the current product lines. Each

value network stage has its own raw material supply cycles, which, in the case of plastic, may be the so-called first or second life of plastic. The technical cycle concerns the processes, materials, and technological innovations by which products are transformed into new materials. Technologies that enable the processing of waste materials into higher-value materials and products are needed. The essential differences from the customers' point of view are the sorting of raw materials and compliance with application-specific quality criteria. Typically, in the second-life plastic cycle, the quality of the raw materials differs from that of virgin plastic. It is also common in recycling that facility processes use several plastic recyclates. It required that the design of value propositions, value creation, value delivery, and value capture mechanisms be developed through collaborative efforts.

Martina and Oskam (2021) studied business models of textile composite products. They identified that principles for recycling and scalable business models require technologies that convert waste materials into higher-value products. Manufacturers need to understand materials science and product design. Automatable technologies are needed. There are take-back systems that guarantee an efficient, predictable, and consistent inflow of materials. There exist take-back systems that guarantee inflow of quality materials. Ecosystem partners have trust for mutual development. Existing technological infrastructures can be expanded. Positive cash flows are generated. Business models are adaptable to legal regimes. Problem-solution fits are developed to match the customer needs and address large markets or markets with growth potential (Martina and Oskam 2021). Based on the interview results, we can state that these principles are also valid for the case study's advanced biocomposites.

3.3 Discussion and Conclusion

The ideal of materials circularity and alignment with sustainability targets can be a challenging balance. The conducted literature review described the motivation and operation of circular design and circular business models. Combined with the interview data, the researchers were able to generate new knowledge on circular business models for biocomposites in the framework of Finnish ABiCo project. The stated research questions 1-3 are answered below:

3.3.1 *RQ1: Which Business Model Elements can be Aligned with the Practical Realities of Circular Business Models of Advanced Biocomposites?*

Guiding principles for circular business model development are visible in the case of biocomposites. There is a sustainability orientation and an extended idea of industrial value-creation among the ecosystem parties. Systemic thinking can be applied. When analysing the studied biocomposites, we can see that there is potential in selected advanced biocomposite materials for circular materials loops. There is room for innovative technologies in this area related to material recognition and sorting on an industrial scale. New innovations can also be expected in end-of-life solutions. One recognized solution is new closed-loop systems. These are high-cost solutions to establish and maintain, but when biocomposite use and recycling are at a substantial level, this kind of recycling loop can be organized. This development is also supported by the growing demand in large end-use segments such as the automotive and construction industries. Before that, other end-of-life solutions will need to be applied. Industrial side streams offer potential as raw materials for biocomposites. Forming industrial sites where symbiosis of different ecosystem players can operate can cut costs in logistics in form of reduced warehousing and transportation costs.

3.3.2 *RQ2: Are There Barriers Limiting the Translation of Circular Design Principles into Viable Business Models for Advanced Biocomposites?*

This co-innovation project on biocomposites states that the lack of circular products and materials within the biocomposites sector can be a limiting barrier. The regulatory environment of recycled plastic products is complex, and recycling targets are demanding. The following systemic barriers exist: a lack of reverse logistics, missing incentives for recyclers, and data gaps that affect material traceability. The collection of plastic waste needs to be increased, and new methods need to be developed. New sorting technologies must be adopted more widely, and further development is needed to achieve good yields and purity across different plastic types. Chemical recycling processes are another approach to plastic recycling, complementing mechanical recycling. Strict regulations not only direct sustainable development but can also increase costs and inefficiencies, such as excessive reporting requirements for businesses. In product and solution marketing, a holistic approach is needed to avoid greenwashing. The end-of-life phase opens new technological development needs and business opportunities in industrial-scale material recognition and material flow management.

Ecosystem dependency rather than firm-level innovation activities. Circular design principles require change towards thinking of the whole material and product cycles from both biological and technical points of view. This is challenging and requires close co-operation with industrial designers. Co-operation can help strengthen customer-supplier relationships as both parties can improve their business and circularity.

From the designers' perspective, new material opportunities need to be brought to knowledge. Different material libraries and solutions for selecting circular materials can help identify the right material choice with sufficient quality. Ideally, design students could be given more knowledge about circular materials and their possibilities in different applications and industrial processes. More material knowledge about biocomposites is needed to grow the demand.

3.3.3 RQ3: How can Value Network Actors Benefit from Implementation of Circular Business Models in Advanced Biocomposites Business?

Demand of biocomposites is growing. This means that all value network actors can develop solutions that meet the growing demand and thus bring new business potential to all value network levels. There are some actor roles that are not that developed yet, and there is lot of room for innovation and new business ideas. All this requires close co-operation between business partners. The ABiCo project consortium, with research institutions and industrial partners, represented an interdisciplinary collaboration that merges technological expertise, industry insight, and market-driven approaches. A combination of deep technical expertise from the industry and research institutions was present.

Ethics Declaration

This study is based on semi-structured interviews with professionals representing different roles of the biocomposite value chain. Participation was voluntary, and the purpose of the study was explained to the respondents. The interview data were anonymised, and no personal or sensitive data are reported in the paper.

AI Declaration

Artificial intelligence tools were used only for language refinement, including grammar correction and improvement of readability. AI was not used to organize literature data, nor interpret interview data, conduct the analysis, or generate the conclusions. All analytical decisions and final interpretations remain the responsibility of the authors.

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