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Open innovation for circular and sustainable business models: case evidence from the bioeconomy sector

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ABSTRACT

This study explores the integration of Open Innovation (OI) models with archetypes of sustainable business in Forest-based Bioeconomy (FBB) companies in the digital age. Utilising a multiple case study methodology, four FBB companies were examined to understand their strategic orientations and sustainability practices. Case studies provide detailed insights into processes and interactions within specific contexts, making them suitable for examining emerging phenomena like the Circular Economy (CE). Although OI, CE, and sustainability have been individually studied, little empirical research explores their intersection in the FBB. Existing literature often focuses on theoretical foundations or isolated applications, neglecting how OI supports circular and sustainable business models in the FBB. Additionally, the challenges and opportunities for FBB companies in the Global South remain largely unexamined, despite their importance in global sustainability transitions. Therefore, this research addresses a significant gap by exploring how companies operating in the forest-based bioeconomy sector exploit OI models to enhance circular and sustainable business models in the digital age. The findings reveal that sustainability approaches are dynamic and overlapping strategies rather than fixed archetypes. The study highlights how OI models facilitate the use of both external and internal knowledge at various stages of innovation, demonstrating that the choice of sustainability archetypes both influences and is influenced by companies' OI models. These insights are valuable for scholars, managers, and policymakers aiming to promote sustainable economic development and environmental stewardship.

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Introduction

As climate change and environmental degradation become more pressing, developing sustainable economic models has emerged as a global priority (DaSilva & Trkman, 2014; Osterwalder et al., 2005). The bioeconomy, which utilises renewable biological resources for the production of goods, services, and energy, offers a promising pathway towards achieving this goal (D'Amato et al., 2017). It aims at leveraging renewable and versatile

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resources to drive economic development while ensuring environmental sustainability. The bioeconomy is seen as a critical component in the transition to a circular economy (CE), where resources are reused, recycled, and maintained within the economy for as long as possible (Carus & Dammer, 2018). Although CE definition varies among scholars resulting in diverse interpretations (Velenturf & Purnell, 2021), Kirchherr et al. (2017) observed that it is often centred on the principles of reduce, reuse, and recycle. This perspective often neglects systemic transformation, sustainability links, and social equity, emphasising only economic and environmental factors. In response, this study adopts a holistic perspective, defining CE as a systemic approach that integrates reduce, reuse, and recycle with sustainable development, emphasising economic, environmental, social, and long-term future dimensions. Scholars have claimed that this approach to the bioeconomy not only mitigates the environmental impacts of economic activities but also fosters innovation and resilience in the face of global challenges (D'Amato & Korhonen, 2021).

The Forest-Based Bioeconomy (FBB) has emerged as a pivotal sector in the global transition towards sustainable and circular economic models (Hetemäki, 2015; Popper et al., 2020). The FBB sector offers a way to leverage forests for economic growth while ensuring ecological sustainability (ECLAC, 2022). In recent years, the circularity of the FBB has garnered increasing attention on a global scale (Carus & Dammer, 2018; ECLAC, 2022). The capacity of this sector to replace conventional inputs with secondary raw materials has positioned it at the forefront of sustainable economic practices.

This study is centred on the intersection of two critical topics framed within the current digital age: Sustainable Business Models and Open Innovation (OI). These dimensions are highly relevant to the FBB sector due to their combined potential to drive systemic transformation. Business models embed sustainability in operations, while OI promotes collaboration and innovation for the FBB. In the digital age, digitalisation plays a crucial role by facilitating data-driven decision-making, enhancing process efficiency, and enabling real-time adaptation to market demands. In the FBB sector, traditional methods now integrate digital forestry systems, optimisation algorithms, and online collaboration tools.

OI involves collaborating with external partners such as partner companies, universities, and broader communities beyond organisational boundaries (e.g., crowdsourcing, citizen science, crowdfunding, and user innovation) to facilitate the exchange of knowledge (Cappa et al., 2019; Dorrego et al., 2024; Franco et al., 2022). (Cappa et al., 2019, 2022; Chesbrough, 2006; Messeni Petruzzelli et al., 2022). Digital technologies like big data, cloud computing, and collaboration platforms can support firms in connecting with external partners and customers to drive innovation for circularity and sustainability (Alcayaga & Hansen, 2025). In today's digital age, OI has become a vital driver of sustainable innovation for organisations. Engaging external partners in collaboration and knowledge exchange in general, and in the innovation process through OI in particular, can significantly enhance innovativeness, performance, and growth (Franco et al., 2022; Hansen & Schmitt, 2021; Messeni Petruzzelli et al., 2022).

While existing literature has explored the individual concepts of OI, CE, and sustainability, there is a clear research gap in the lack of comprehensive empirical studies that examine their intersection, specifically within the FBB sector (D'Amato et al., 2020; Dorrego-Viera et al., 2025). This gap is particularly pronounced in the

context of the Global South, where socio-economic and environmental challenges intersect, creating unique conditions for innovation (Salvador et al., 2022). Addressing this gap provides an opportunity to offer actionable insights that are both context-sensitive and scalable to other regions (Salvador et al., 2023). This study uniquely contributes to the literature by investigating how FBB companies integrate OI models to navigate sustainability transitions, emphasising the dynamic and overlapping nature of CE and their interdependence with OI strategies. Consequently, this article is intended to address the following research question: *How do companies operating in the forest-based bioeconomy sector exploit OI models to enhance circular and sustainable business models in the digital age?*

The research adopts a multiple case study approach, analysing four companies in the FBB sector. This method is chosen for several reasons, as supported by prior research in CE and innovation (Hansen & Revellio, 2020; Urbinati et al., 2020). A phased approach was implemented, comprising three stages to deeply investigate and understand the dynamics of the selected companies. Considering the contemporary relevance of the topic, qualitative interviews were conducted to gather insights and experiences from key informants.

By focusing on the underexplored context of the Global South, this research offers novel insights into the strategic orientations, challenges, and opportunities of FBB companies in regions with abundant natural resources and distinct socio-economic dynamics. These findings advance our understanding of how OI facilitates sustainable innovation and strategic adaptation in the digital age, providing actionable insights for scholars, policymakers, and practitioners. The findings indicate that sustainability practices are best viewed as a dynamic and overlapping range of strategies rather than static archetypes. Dynamic strategies are characterised by their adaptability and responsiveness to evolving environmental, social, and market conditions, enabling organisations to continuously refine and integrate diverse approaches to achieve sustainability goals in a flexible and innovative manner. Similarly, OI models reveal how companies utilise both external and internal knowledge at various stages of innovation. By integrating these perspectives, it becomes evident that the selection of sustainability archetypes both influences and is influenced by the companies' OI models. In the digital age, these interactions are shaped by tools for efficient knowledge management, real-time collaboration, and precise resource allocation, amplifying the transformative potential of the intersection between OI and sustainability. By examining it, we aim to provide valuable insights for scholars, managers, and policymakers. As such, this study offers a novel contribution by integrating sustainability-focused business model archetypes with OI models to examine circularity in the FBB. Unlike previous research, which has largely treated these concepts separately, our approach provides a comprehensive framework that highlights their dynamic interplay. By incorporating digital transformation as a key enabler, this study not only advances theoretical understanding but also offers practical insights into how firms can leverage digital tools to enhance circular strategies. Furthermore, our mixed-methods approach, combining qualitative analysis with quantitative assessments, allows for a more nuanced exploration of how sustainability archetypes evolve in response to market and policy dynamics. This interdisciplinary perspective broadens the scope of existing research and provides a foundation for future studies on circular business models in the digital era.

The article is structured as follows: Section 2 examines the conceptual background of this research, focusing on the existing literature that addresses the circular bioeconomy, sustainable business models, and the intersection with OI models. Section 3 introduces the case method, while Section 4 establishes the arguments for the sector and the cases selected for this study. The main findings are presented in Section 5, to leave room for conclusions and implications in Section 6.

Theoretical background

Sustainability and circularity in the bioeconomy

Achieving the Sustainable Development Goals requires a major shift in economic models and production-consumption systems, with the private sector playing a key role (Dorrego-Viera et al., 2023). The bioeconomy and CE, endorsed at policy, research, and industrial echelons, emerge as potent contributors to these sustainability transformations.

The CE, rooted in five decades of ideas surrounding industrial ecology and metabolism, directs its focus towards enhancing the efficiency and recycling capacity of the contemporary consumption-production system. Strategies encompass input reductions, eco-design, improved practices, and waste reuse and recycling (Kirchherr et al., 2017). Conversely, the bioeconomy, a more recent concept, advocates the shift from fossil-based industrial inputs to biomass-based alternatives, emphasising the sustainable utilisation of renewable resources (Korhonen et al., 2018).

Critical drivers for the development of both the CE and bioeconomy include technological innovation, regional capacity development, knowledge centres, and industrial collaboration. Notably, in Uruguay, expectations for circular and bioeconomy strategies are predominantly linked to the FBB sector, with less emphasis on clean technology, resource efficiency, and recycling (Antikainen et al., 2017). Nevertheless, the tangible contribution of these concepts to resolving sustainability challenges remains a subject of extensive debate (D'Amato et al., 2017; Kröger & Raitio, 2017). One notable concern is the rebound effect, where efficiency gains paradoxically lead to increased production and consumption, potentially negating environmental benefits (D'Amato & Korhonen, 2021; Lowe et al., 2024; Zerbino, 2022).

Similarly, critiques of the bioeconomy emphasise its inability to confer environmental benefits solely through the substitution of fossil-based resources with bio-based alternatives, particularly if the latter are not managed sustainably (Weiss et al., 2012). Both the CE and bioeconomy, being resource-centric, often overlook synergies and conflicts with broader ecological processes and ecosystem services in the digital age (D'Amato et al., 2017). In the case of the wood industry, the circular transition often resembles a cascading use of goods rather than a fully circular approach to end-of-life materials (Ellen MacArthur Foundation, 2013). This reliance on sequential utilisation may fail to address critical environmental trade-offs, such as resource depletion or overharvesting (Dossa & Miassi, 2024). Without rigorous safeguards, such practices risk undermining the long-term sustainability of forest ecosystems.

The circular bioeconomy concept goes beyond these limitations. It integrates circularity principles (e.g., biomass cascading, waste hierarchy, resource efficiency) with new

approaches like sustainable sourcing and a shift from ownership to usage (Bezama, 2016; Ciccarese et al., 2014). This holistic approach is articulated as 'more than bioeconomy or circular economy alone' (Hetemäki, 2015, p. 14). However, the circular bioeconomy is not without its challenges. For instance, poorly designed biomass cascading systems or insufficient attention to territorial inequalities could exacerbate environmental and social disparities, particularly in regions with limited governance capacities (Miassi & Dossa, 2024).

Agriculture, forestry, and related industries are key to the circular bioeconomy, supplying renewable resources and fostering research and innovation (Angelshaug et al., 2023). In the digital age, the adoption of advanced monitoring tools, such as IoT-enabled sensors and blockchain-based traceability systems, could mitigate some of these risks by ensuring more transparent and accountable resource use. High expectations in Uruguay and the Global South specifically hinge on the renewal of the forest sector to facilitate the transition to a circular bioeconomy (ECLAC, 2022).

Sustainable business models

Sustainable business models remain a subject of scholarly discourse, with scholars offering varying definitions (DaSilva & Trkman, 2014; Richardson, 2008; Teece, 2010). Richardson (2008) positions the business model as a distinct unit of analysis at the company level, comprising three core components: value proposition, creation and transfer, and capture. The value proposition encompasses addressing target customers' needs, representing a company's competitive advantage through product/service offerings and customer relationships. Value creation and transfer involve a company's resources, technologies, and relationship network, culminating in a competitive advantage and the creation of customer value. Value capture pertains to the cost structure and revenue streams. Every company, consciously or not, operates within a business model, converting customer needs into a competitive advantage through the utilisation of strategic resources (Teece, 2010), especially in the current digital age (Gawer, 2022; Urbinati et al., 2022).

Choosing the right business model, as emphasised by Teece (2010), is critical for fostering innovation and supporting customer value creation. Within the context of sustainable production-consumption systems, innovative business models – whether more incremental or radical (Schaltegger et al., 2012) – are recognised as pivotal drivers of transformation (Antikainen et al., 2017; Hetemäki, 2015; Urbinati et al., 2023) and can change industries through co-evolution (Schaltegger et al., 2016). A strong sustainability-focused business model creates value for customers and stakeholders while preserving or restoring natural, social, and economic capital (Sassanelli et al., 2019). In essence, sustainable business models align company objectives with global sustainability goals (Bocken et al., 2014).

Boons and Lüdeke-Freund (2013) advocate for extending business value propositions to encompass social and ecological value in addition to economic value. Sustainability considerations can be integrated into value creation and transfer processes by utilising renewable resources, developing sustainable technological innovations, engaging with responsible suppliers/contracts, and promoting more sustainable consumption.

Moreover, sustainable value capture necessitates the fair redistribution of income and expenditure between parties (Boons & Lüdeke-Freund, 2013).

However, while the theoretical frameworks surrounding sustainable business models are robust, there is limited empirical evidence on their practical implementation in the CE (Fraccascia et al., 2021) and in specific sectors, particularly in the Global South. This gap is further amplified in resource-based industries such as forestry and the bioeconomy, where contextual factors such as governance capacities, market dynamics, and cultural norms may significantly influence the adaptation and success of these models.

Sustainable business model archetypes refer to categorised sets of mechanisms and solutions designed to support the creation of business models centred on sustainability (Bocken et al., 2014). These archetypes aim to establish a shared framework that facilitates the advancement of sustainable business models in both academic research and practical applications. Bocken et al. (2014) proposed eight archetypes of sustainable business, categorised into three main business model innovations: technological, social, and organisational. Technological innovations encompass efficiency, waste recycling, and the utilisation of renewables. Social innovation-driven archetypes involve promoting product/service usage over ownership, adopting higher environmental and social stewardship roles, and encouraging sufficiency and frugality in consumption. Archetypes grounded in innovative organisational structures entail repurposing business for societal and environmental benefits and developing scalable solutions with positive social or environmental impacts (Bocken et al., 2014).

Despite the wide adoption of these archetypes in theoretical studies, their application in practice often remains fragmented and context-dependent. For example, the implementation of sufficiency or frugality-driven models may encounter resistance in consumption-driven economies, while renewable-focused archetypes may require significant technological and infrastructural investments that are not universally accessible. Research rarely explores how these archetypes interact in complex systems like the forest-based bioeconomy, where sustainability transitions involve multiple innovations.

In line with Bocken et al. (2014), we have constructed a conceptual framework to facilitate the interpretation of our findings (Figure 2), an iterative process aligning theory with empirical data. By bridging this theoretical-practical gap, the study contributes to the understanding of sustainable business models in resource-intensive sectors, offering insights into how global frameworks can be adapted to regional and sectoral contexts.

Open innovation and sustainability-oriented innovation

In the digital age, OI and Sustainability-Oriented Innovation have emerged as crucial approaches in stimulating academic discourse, garnering substantial attention from policymakers, practitioners, and global societies (Hansen et al., 2009; Hansen & Grosse-Dunker, 2013; Urbinati et al., 2023).

OI, as theorised by Chesbrough (2006), examines how firms extend their innovation processes beyond internal boundaries, leveraging external technology and knowledge flows to enhance the success of innovation endeavours. The manifold benefits associated with OI include the acceleration of time-to-market processes, augmentation of firms' knowledge base, enhanced market success for innovative products, expanded access to foreign markets, and the sharing of risks and costs (Urbinati et al., 2021).

However, Lazzarotti et al. (2010) argue that OI is often treated as strictly open or closed, ignoring its spectrum of openness. Consequently, this article introduces a perspective that considers two underexplored variables representing the degree of openness: the number and type of partners (partners variety) and the number and type of phases of the innovation process open to external contributions (innovation phase variety). This approach characterises companies under investigation into four OI model profiles:

- Open Innovators: Engaging with a diverse set of partners across multiple phases of the innovation process.
- Specialised Collaborators: Opening only a limited part of the innovation process to a diverse array of partners.
- Integrated Collaborators: Collaborating with a restricted set of partners throughout the entire innovation funnel.
- Closed Innovators: Opening a minimal portion of the innovation funnel to a very limited set of partners.

As a result, Figure 1 summarises the conceptual framework that structures this research in a three-dimensional approach: (i) the Archetypes of Sustainable Business; (ii) the Business Model Dimensions; and (iii) the Degree of openness.

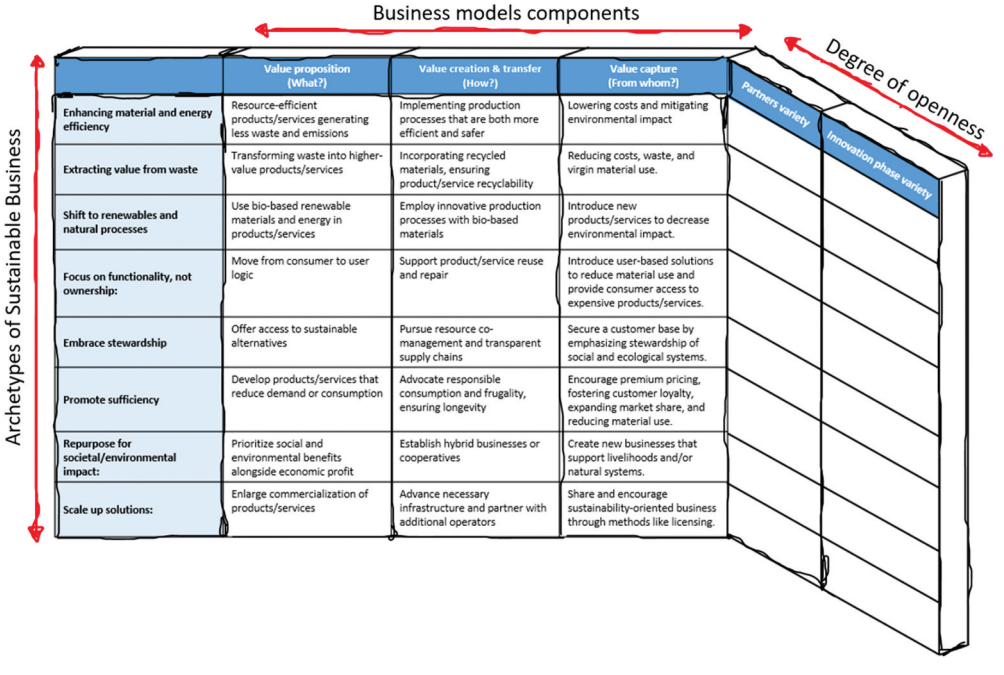


Figure 1. Conceptual framework.

Methodology

Multiple case studies

The study uses a multiple case study methodology to examine four companies in Uruguay. Following Creswell and Poth (2016), this method explores real-life systems, collecting detailed, in-depth data from various sources, and presenting case descriptions and themes (p. 97). This methodology is well-suited to exploring how companies integrate OI models to achieve circular and sustainable transformations. The complex and context-specific nature of this inquiry requires an in-depth exploration of real-world practices and the ability to identify both commonalities and variations across cases, a strength inherent to the multiple case study approach (Yin, 2009).

Unlike other research methods, such as large-scale surveys or experiments, case studies allow for a nuanced understanding of processes and interactions within their specific contexts, making them ideal for exploring emerging phenomena like the circular bioeconomy (Yin, 2009). This study employs a qualitative approach to explore complex phenomena.

Exploratory multiple case study analysis has been applied in relevant research in CE and innovation (Hansen & Revellio, 2020; Urbinati et al., 2020). It allows for data examination within and across situations, predicting contrasting or similar results (Yin, 2009). Multiple case studies enable cross-case comparisons, providing valuable insights (Stake, 2013). The multiple case study method was chosen for its capacity to investigate variations and commonalities across cases, offering a robust framework for analysing how FBB companies integrate OI models to drive circular and sustainable business transformations.

Additionally, the choice of this methodology addresses gaps in the current literature on sustainable business models in resource-intensive sectors like forestry, where empirical insights remain scarce. By using multiple cases, the study also enhances the transferability of findings, as cross-case comparisons can highlight patterns and practices that transcend individual contexts, deepening our understanding of the broader sectoral dynamics.

This approach addresses gaps in theory and contributes to understanding phenomena (Eisenhardt & Graebner, 2007). It aligns with the recommended number of cases (Gustafsson, 2017). Focused and systematic data collection is crucial for theory-building case studies (Mintzberg, 1979), emphasising defining the unit of analysis (Yin, 2009) and using diverse data sources, including interviews, observations, and archival materials (Boyer et al., 2009). This method is suitable for qualitative analyses and theory-testing, enhancing understanding of complex phenomena (Yin, 2009). This approach is well-aligned with the research objective of understanding nuanced practices, strategies, and outcomes, allowing for both theoretical development and empirical insights. By examining multiple cases, the study enhances the validity and generalisability of findings, as cross-case comparisons can identify shared patterns and unique practices that deepen understanding of the sector's dynamics (Stake, 2013). Real-time data collection mitigates weaknesses of retrospective reconstruction and reinterpretation errors (Alblas & Wortmann, 2009). Steps and activities for the case study analysis are outlined in Table 1. Data analysis occurs incrementally with data collection (Urbinati et al., 2020),

Table 1. Results.

	Business Model Components	Archetypes of Sustainable Business	Degree of Openness	OI Model	Key Insights
Company A	***Value proposition:*** Premium-grade Pine and Eucalyptus sawn timber products designed for diverse applications and utilisation in both national and international markets. ***Value creation & transfer:*** the company employs renewable resources, and certified raw materials. It is observed certain levels of technological backwardness, although the facilities have been improved. In relation to its partners, due to its long prestigious track record the firm has become a reference for the market and the sector, as well as for other agents in the community. ***Value capture:*** the company offers cheaper prices than other competitors for specific segments of the market. In addition, this company owns a significant portion of the forests that provide its industrial venue. Although it is not a recent development, the fact that the company has developed a scaling-up business is a source of value capturing.	• ***Enhancing material and energy efficiency*** • ***Shift to renewables and natural processes*** • ***Embrace stewardship***	***Partners variety:*** The company engages with a broad spectrum of partners, leveraging extensive industry experience for strong connections within the extended value chain. Despite this, innovation collaborations are limited, primarily involving the Uruguayan Technological Laboratory (LATU) and the National Agricultural Research Institute (INIA). Beyond these, only a handful of additional partners contribute to various stages of production ***Innovation phase variety:*** The company engages across various facets of the forest-based bioeconomy production within the country. While overseeing significant forestry ventures that supply certified resources to its industrial plant, the company operates within a structured innovation framework comprising distinct phases. However, it does not emerge as a pioneering entity in innovation within either its forestry settlements or industrial facilities. Instead, it is more aptly described as a follower in the realm of innovation at these different stages	***Integrated Collaborators***	**Focused, Established Practices Supported by Selective External Partnerships**: Company A employs a combination of sustainability archetypes to reinforce its market position and commitment to environmental and social responsibility. By integrating **'Embrace Stewardship'**, the company ensures that its products are sourced from certified forests, aligning with rigorous environmental and social standards. The **'Shift to Renewables and Natural Processes'** archetype is reflected in its efforts to align with market trends favouring renewable materials. The company also practices **'Enhancing Material and Energy Efficiency'** to optimise resource use and minimise waste. As an **'Integrated Collaborator'**, Company A maintains a structured yet selective approach to external partnerships, focusing on established practices and incremental improvements rather than pursuing novel or disruptive innovations. This strategic choice supports a stable and reliable model for achieving sustainability goals while maintaining a strong reputation in the industry.

(*Continued*)

Table 1. (Continued).

	Business Model Components	Archetypes of Sustainable Business	Degree of Openness	OI Model	Key Insights
Company B	***Value proposition:*** Plywood obtained from forests managed sustainably, guaranteeing a reliable and environmentally aware source. ***Value creation & transfer:*** the firm operates renewable resources, and certified materials. In addition, it is well focused on being energy-efficient by producing part of the production requested power from its own waste material. New production technology, with less inputs and outputs needed and safer processes. Continuous technological catch-up. In terms of partnership, the company seems to be well connected to different stakeholders, such as Supply-chain agents, workers unions, and public institutions. ***Value capture:*** for the company the competitive prices, and the higher prices due to branding are relevant. In addition, lower costs from outsourcing services and significant investments in land, plantations, and renewable energy production based on biomass are being put in place. For other partners, it is a company with strong connection to international markets. Solid reputation as an actor of the global value chain.	• ***Enhancing material and energy efficiency*** • ***Extracting value from waste*** • ***Shift to renewables and natural processes*** • ***Embrace stewardship*** • ***Promote sufficiency*** • ***Scale up solutions***	***Partners variety:*** The company has implemented a robust strategy that aligns its operations with diverse stakeholders within the extended forest-based bioeconomy value chain. Collaborating with farmers, civil society organisations, research institutions like LATU and INIA, universities, international consultants, auxiliary producers such as Beekeepers or livestock producers, and public institutions, the company advocates for an inclusive open innovation approach to research and development. ***Innovation phase variety:*** the company has emerged as a highly significant participant in Uruguay's forest-based bioeconomy, operating across various segments of the value chain. Leveraging its own forests as a source of renewable resources, it has created opportunities for innovation, establishing a distinctive innovative profile across different production stages, from nursery capabilities to international market expansion.	***Open Innovators***	**Extensive External Collaborations Supporting Diverse Sustainability Strategies**: Company B's approach reflects a broad and inclusive engagement with a wide range of external partners, including farmers, researchers, and public institutions. By employing **'Enhancing Material and Energy Efficiency'**, the company maximises resource use and minimises waste in its production processes. Additionally, their efforts to **'Extract Value from Waste'** are realised through innovative R&D projects aimed at developing new products from residual materials. As an **'Open Innovator'**, Company B's extensive network and proactive engagement across various innovation phases enable it to explore and implement multiple sustainability archetypes, demonstrating that a wide range of collaborations can drive comprehensive and effective sustainability initiatives.

(*Continued*)

Table 1. (Continued).

	Business Model Components	Archetypes of Sustainable Business	Degree of Openness	OI Model	Key Insights
Company C	*Value proposition:* Structural housing constructed with Mass Timber derived from wood, offering an eco-friendly solution that blends lightweight design with a significant load-bearing capacity. *Value creation & transfer:* The company utilises renewable resources, and certified materials. Moreover, it operates pine, a type of wood that represents more an exception than a rule in the industrial sector of the country. The enterprise foresees its sawmills becoming regional exemplars in Mass Timber production by setting the largest plant of this kind in the whole South American region, which is called to be aligned with the objectives of the United Nations SDGs. *Value capture:* the company's innovative spirit has taken it to central seen of the market and the sector, being nowadays a reference in terms of wood-based construction for the country. Income from new market areas, fast idea commercialisation and good branding. For others, reducing environmental impact in production, broader social benefits from environmental health.	• *Enhancing material and energy efficiency* • *Extracting value from waste* • *Shift to renewables and natural processes* • *Embrace stewardship* • *Promote sufficiency*	*Partners variety:* The company emphasises its commitment to adopting an open innovation approach in its Research and Development (R&D) practices. This commitment is embedded in its business model, establishing connections with research centres, universities, design hubs, scientific development units, and other entities within its supply chain at both national and international levels. Despite the recent commencement of its advanced industrial plant, the company has forged a robust network of innovative partners, expressing confidence in their potential contributions to the company's success. *Innovation phase variety:* The company concentrates on the industrial phase of production, primarily centred on the mechanical processing of wood. While the range of innovation phases may be comparatively narrower than other companies examined in this study, it stands out as one of the most disruptive entities identified in this research.	*Specialized Collaborators*	**Specialised OI Practices Driving Disruptive Innovations within a Focused Domain**: Company C embodies a deep commitment to **'Promote Sufficiency'** through the creation of durable, long-lasting products and **'Shift to Renewables and Natural Processes'** by utilising forest-based resources. Its **'Specialised Collaborator'** OI model focuses on building strong partnerships with research institutions and design hubs to drive specialised innovations in mechanical processing. This specialised focus allows the company to push the boundaries of what is possible in the industry, setting new standards for sustainability and technological advancements. The company's approach underscores that intense specialisation in a specific domain of the value chain can lead to transformative innovations and significant industry impacts.

(*Continued*)

Table 1. (Continued).

	Business Model Components	Archetypes of Sustainable Business	Degree of Openness	OI Model	Key Insights
Company D	***Value proposition:*** Wood veneer, produced in two variations. Firstly, Eucalyptus Grandis (Rose gum) is utilised for crafting outdoor furniture, decoration, mouldings, interior structures, unwinding, and wooden floors. Secondly, Pine Taeda and Pine Elliotii serve diverse purposes such as construction, sawing, unwinding, and indoor furniture. ***Value creation & transfer:*** the business manages renewable resources, and certified materials. It provides holistic solutions from planting to the industrial phase, prioritising employee safety, environmental responsibility, legal compliance, and ethical principles. The company's state-of-the-art industrial plant attains full energy independence by utilising wood waste generated in its production processes. It is also part of regional network of forest-based enterprises. ***Value capture:*** The firm offers concrete proof strategically utilised to improve company operations through innovative and reciprocal feedback mechanisms. For others, reducing environmental impact in production, turning industrial by-products into higher value products	• ***Enhancing material and energy efficiency*** • ***Extracting value from waste*** • ***Shift to renewables and natural processes*** • ***Embrace stewardship*** • ***Scale up solutions:***	***Partners variety:*** the enterprise exhibits a distinct innovation approach, primarily characterised by a strong emphasis on closed innovation. The company has established a robust Research and Development (R&D) unit that plays a pivotal role in driving innovation within the organisation. By relying on internal resources and expertise, the company seeks to optimise its innovation processes and develop proprietary solutions tailored to its specific needs. This closed innovation model allows the company to maintain a tight control over its intellectual property, fostering a culture of secrecy and proprietary knowledge development within its organisational boundaries. The R&D unit is considered a key asset, contributing significantly to the company's technological advancements and maintaining a competitive edge in the market. ***Innovation phase variety:*** the company has undergone a notable evolution in its innovation phases, transitioning from a traditional forestry producer to a more dynamic industrial player. This transformation has introduced diverse stages of innovation within the company, ranging from optimising forestry practices to adopting advanced technologies in the industrial phase. The upgrading process has positioned the company as a multifaceted entity engaged in various facets of the value chain. While the innovation landscape may have evolved due to this shift, the company remains focused on leveraging its internal capabilities to drive advancements across different stages of its operations, showcasing a nuanced approach to innovation within the context of its industry. As a result, they open a marginal fraction of the innovation pipe to a very restricted set of partners.	***Closed Innovators***	**Internal R&D Processes Enabling Deep, Strategic Sustainability Efforts**: Company D's strategy reflects a commitment to **'Shift to Renewables and Natural Processes'** and **'Scale-up Solutions'**, leveraging forest resources for sustainable production and planning for future industrial developments. Their **'Closed Innovator'** model highlights a focus on internal R&D capabilities to drive innovation within the company. By maintaining control over its intellectual property and concentrating on internal research and development, Company D can implement advanced technologies and develop tailored solutions for its specific needs. This closed approach supports comprehensive sustainability efforts and efficient scaling of production processes, illustrating how strong internal capabilities can facilitate both innovation and sustainability objectives.

acknowledging the method's increasing popularity despite its limitations (Gustafsson, 2017).

The sector and the cases chosen

We chose the FBB sector in the Global South as specific context in the bioeconomy. In Uruguay, the FBB sector holds significance as a key economic driver and a notable source of foreign direct investment, experiencing substantial expansion based on vast eucalyptus plantations and the establishment of large-scale multinational pulp mills. Although economic priorities dominated, environmental policies gradually integrated over three decades amid ongoing conflicts (Kefeli et al., 2023). The Uruguayan FBB sector thus offers a compelling context for the development of public discussions about the sustainable outreach of this dynamic but controversial value chain as an emerging subsystem.

Popper et al. (2020) state five key FBB areas (FBAs) in Uruguay such as forest management, mechanical wood processing, fibre-based biomaterial processing, biorefining and bioenergy. FBAs are the cornerstones of forest cluster, which relies on sustainable and resource-efficient use of forest biomass. While the country's value chain expansion primarily hinges on fibre-based biomaterial processing, particularly in cellulose pulp production, several studies underscore the importance of mechanical wood processing as a trajectory towards a more value-added development model (Bombeck et al., 2017; De Corato et al., 2018; Dieste et al., 2019). In addition, proponents argue that the mechanical wood processing FBA holds significant potential to embed sustainability at the core of the equation, providing opportunities for the implementation of circular bioeconomy production models (D'Amato et al., 2020; Näyhä, 2019; Popper et al., 2020). The mechanical wood processing segment showcases both value-added potential and opportunities for aligning business models with CE implementation. Investigating cases in the Global South is particularly important, as these regions often possess abundant natural resources and face unique socio-economic challenges. The mechanical wood processing segment, a critical component of the country's FBB sector, serves as a lens through which we examine the transformative journey towards a more value-added and circular approach

Case selection

We selected four case companies following a deliberate and contextually grounded logic:

(1) Bioeconomies in the Global South: As bioeconomies gain strategic importance globally, their development in the Global South is particularly significant due to these regions' rich natural resources and unique socio-economic contexts (ECLAC, 2022).
(2) Relevance of the FBB: The FBB has been identified as a critical value chain within bioeconomies, offering significant potential for sustainable development and economic growth (D'Amato et al., 2020).
(3) Potential for Circular Transition in Mechanical-Wood Processing: The mechanical-wood processing segment is recognised for its ability to enable a circular transition by replacing virgin inputs with secondary raw materials, promoting more sustainable production systems (Popper et al., 2020).

(4) Uruguay as a Relevant Empirical Context: Uruguay presents an ideal case for this research due to the significant expansion of its FBB sector. This growth highlights opportunities for advancing the mechanical-wood processing industry as a cornerstone of the country's bioeconomy and CE strategies (Dieste et al., 2019).
(5) Strategic relevance of companies in the industry: The four selected companies were identified as key players within Uruguay's FBB value chain and the mechanical-wood processing sector. Their strategic roles and innovative practices make them pivotal examples for exploring the intersection of OI and sustainability in this context (Table 2).

Data collection & analysis

Considering the contemporaneity of the subject under investigation, qualitative interviews were employed to capture the knowledge and experiences of relevant informants. Qualitative research, a well-established tool in management and business administration research (Gummesson, 1991), allows for an in-depth dialogue that can adapt to emerging or novel topics (Kvale & Brinkmann, 2009). The study chose Uruguay as an empirical context due to its recent circular and bioeconomy strategies (Oficina de Planeamiento y Presupuesto, 2019a, 2019b; Dieste et al., 2019, 2021) Despite implementation challenges, businesses of various sizes and segments within Uruguay are actively fostering new growth through sustainability-driven business models (Popper et al., 2020).

The methodological design involved three distinct phases to comprehensively explore and understand the dynamics of the selected companies within the FBB sector.

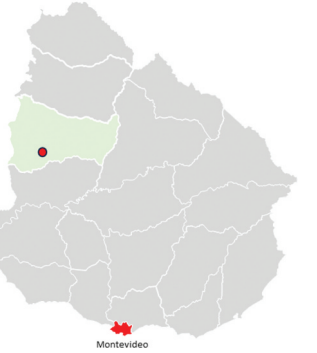
Phase 1: literature review and academic exploration

The initial phase involved an extensive review of academic and grey literature pertinent to the circular bioeconomy sector and its value chain. Building on prior research, a broad search strategy was employed comprising three key stages: (i) defining the scope of the review (Colicchia & Strozzi, 2012; Denyer & Tranfield, 2009); (ii) identifying relevant studies through suitable databases and search tools (Ali et al., 2017; Colicchia et al., 2019); and (iii) applying inclusion criteria to assess and select studies, resulting in a curated set of papers (Ali et al., 2017; Kembro et al., 2014). In this study, data was retrieved from the Scopus database, recognised as one of the most extensive abstract and citation repositories for peer-reviewed literature (Mongeon & Paul-Hus, 2016; Zhu & Liu, 2020).

Following Colicchia et al. (2019) we established various inclusion criteria to sustain transparency in the selection process and to assess the significance of the papers that were chosen. These criteria state that:

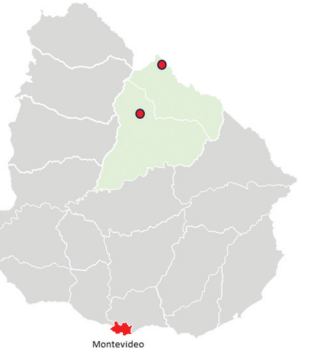
- Selection based on key Boolean words such as 'circular bioeconomy', 'forest-based bioeconomy', 'sustainable bioeconomy', 'circular bioeconomy & open innovation', and related terms.
- Articles published in peer-reviewed journals, which are considered to be of higher quality than non-peer-reviewed articles.
- Selection of papers without restriction on publication year, keeping the widest possible time period to fulfil with the purpose of the research.

Table 2. Companies description.

	Description	Main industrial production	Location
Company A	Company A, an investment vehicle established a century ago in 1925, operates as a forestry enterprise. The commencement of forestry activities dates back to 1964, marked by the acquisition of the initial 6,000 hectares in Paysandú for the cultivation of pine and eucalyptus trees. Presently, the company engages in forestry, industrial, and livestock operations across a total expanse of 18,000 hectares, providing employment for more than 300 individuals, both directly and indirectly. Company managers emphasise the implementation of a '100% technified sawmill line from the entry of the log to its loading on the container'. Significant transformations occurred in the company's industrial infrastructure in 2008 through a substantial investment in a sawmill featuring drying chambers. This modernisation initiative aimed to boost production and exports, resulting in the establishment of a cutting-edge sawmill and drying facility. Notably, 80% of the energy required for wood drying is sourced from wood chips, a byproduct obtained through the crushing of wood in the sawmill. This byproduct serves as an energy source to produce steam, facilitating the drying process through heat exchangers. Additionally, the company utilises natural gas in a separate drying chamber due to the boiler reaching its maximum capacity. Approximately 15 years ago, a strategic shift in the export commercial policy occurred, focusing on enhancing the added value of tree production and industrialisation. This approach encompasses the processing of sawn or remanufactured, calibrated, and dried wood tailored for furniture and industrial applications. The company expanded its market presence globally, with concentrated exports to countries such as Vietnam, China, Indonesia, Malaysia, Taiwan, the United Arab Emirates, the United States, and Saudi Arabia.	The firm produces and sells high quality products of both Pine and Eucalyptus sawn timber which is intended for various applications and uses of the national and international market.	

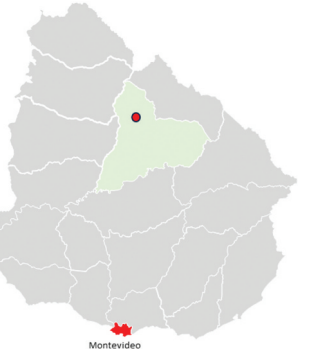
(*Continued*)

Table 2. (Continued).

	Description	Main industrial production	Location
Company B	Company B is under the ownership of a consortium comprising long-term institutional investors. In 2017, a leading multinational timberland investment consortium acquired one of the largest Uruguay timberlands and a manufacturing facilities. This leading multinational stands as one of the oldest and largest Timberland Investment Management Organizations, managing assets totalling US$ 5.2 billion predominantly in the U.S. and Latin America. This firm is a prominent timberland and forest products company in Uruguay, boasts over 20 years of operation and ownership of 120,000 hectares of timberland in northeastern and north-central Uruguay. The company's operations encompass a seedling nursery, cogeneration facility, and plywood and veneer manufacturing facility. Currently, over 750 personnel work across departments in Tacuarembó, Rivera, Cerro Largo, Treinta y Tres, and Montevideo. The company's industrial phase commenced in 2004 with the construction of a plywood mill in Tacuarembó, inaugurated in June 2006. Subsequent expansions were announced in Tacuarembó, involving substantial investments in land, plantations, and renewable energy production based on biomass. Recently, the firm has disclosed an investment of approximately US$ 136 million to construct its third industrial plant in Uruguay, slated to generate over 300 jobs and expand production capacity to nearly 500,000 cubic metres. If realised, this would position Uruguay as the second-largest plywood producer in Latin America based on current figures. The firm maximises the utilisation of log components, transforming them into plywood and repurposing waste as biofuel for the plant's boilers and to energise the industrial processes. Situated in Tacuarembó, the manufacturing plant incorporates a specialised 10 MW power facility generating steam and electricity, achieving full energy efficiency. Notably, the company produces surplus bioenergy, which is supplied to the Uruguayan electricity grid, showcasing its commitment to sustainable and efficient energy practices.	The primary industrial output of the company is Plywood, sourced from sustainably managed forests, ensuring a dependable and environmentally conscious supply. This plywood, constructed with perpendicularly arranged veneer and bonded using phenolic adhesive, is distinguished by its structural attributes, stability, resilience, and aesthetically pleasing appearance. However, there are serious concerns about the circularity capacity of plywood. Although it is produced using wood waste, this represents a one-off recycling approach. Consequently, despite the company's presentation of plywood as a main circular product, authors do not consider it truly circular due to its inability to be recycled further.	

(*Continued*)

Table 2. (Continued).

	Description	Main industrial production	Location
Company C	Company C specialises in converting forest products into sustainable construction materials, aligning its practices with Circular Economy principles. Positioned as a leader in the circular bioeconomy, its mission is to advance timber solutions and sustainable building materials both locally in Uruguay and on a global scale. The company envisions its sawmills serving as regional models for Mass Timber production, in line with the United Nations Sustainable Development Goals. As a subsidiary of a construction systems-focused business group with investors from Uruguay and the US, Company C gained prominence in 2021 through its acquisition of another well-known foest-based industrial plant in Tacuarembó, Uruguay. This strategic move indicated a transformative moment in the industry under the promise of significantly increase wood exports in the country. Subsequently, the company embarked on two key initiatives: expanding timber production and establishing the largest Mass Timber plant in South America. This facility contributes to the economic revitalisation of northern Uruguay, providing employment for over 250 individuals and representing a substantial industrial investment for the region. Mass Timber, a wood processing system facilitating the construction of tall buildings, residences, sports centres, medical facilities, schools, and other projects, plays a pivotal role in promoting environmentally sustainable housing construction. Despite gaining traction in 1990s Europe, Mass Timber has yet to fully thrive in Latin America, despite growing environmentally friendly initiatives in transportation, food, and energy. With the traditional construction sector responsible for 40% of greenhouse gas emissions (IEA, 2023), there is a growing acceptance of sustainable solutions. Company C's CFO emphasises Uruguay's competitive forestry resources and the potential of Mass Timber to reduce CO2 emissions by 2030, framing homes as future CO2 repositories. In terms of innovation collaboration, the company primarily focuses on integrating technology and developing skills in collaboration with specific suppliers. However, it aspires to establish robust partnerships with local and international stakeholders, recognising the importance of a strong network connecting the company to research and training institutions.	The company's primary product encompasses wood-based structural housing utilising Mass Timber, presenting an environmentally friendly solution that harmonises lightweight design with a substantial loading capacity. The panel system affords flexibility, facilitating replacement when required.	

(*Continued*)

Table 2. (Continued).

	Description	Main industrial production	Location
Company D	The company operates in Uruguay, Brazil, and Chile, providing asset management and forestry services. It delivers comprehensive solutions, emphasising the safety and well-being of employees, responsible environmental stewardship, compliance with legal requirements, and ethical principles. Originating as a forestry services company in Uruguay in 2000, it initially focused on weed control, later expanding and diversifying its services. Presently, the company offers a range of services throughout all stages of forest growth, fund development and management, and the administration of forestry and agricultural assets. Its presence extends to Chile since 2007 and Brazil since 2010, collectively managing over 100,000 hectares across the three countries. The specialised subsidiary focused on wood sales caters to a global clientele, serving over 40 customers spanning Vietnam, China, South Korea, Japan, Malaysia, the Philippines, Indonesia, and India. Recently, the company made a substantial investment of U$S 6 million in establishing a new plywood production plant in Treinta y Tres. This cutting-edge industrial facility achieves complete energy self-sufficiency through the utilisation of wood waste generated during its production processes. As affirmed by the Chief Operating Officer, the waste generated is efficiently harnessed to meet the company's entire energy requirements, exemplifying a closed-loop strategy for resource efficiency. Moreover, a primary objective of this industrial plant is to assess the quality of products derived from the company's forestry initiatives. This initiative aims to provide tangible evidence that can be strategically applied to enhance the company's operations through innovative and reverse feedback mechanisms.	The main product of the company is wood veneer, which is manufactured in two variants. On the one hand, using Eucalyptus Grandis (Rose gum), which is employed in the production of outdoor furniture, decoration, mouldings, interior structures, unwinding, and wooden floors. On the other hand, Pine Taeda and Pine Elliotii are used for various purposes such as construction, sawing, unwinding, indoor furniture, etc.	

- Articles published in English, due to it provides our investigation with linguistic homogeneity.

The initial search yielded 120 academic papers and reviews alongside 14 non-academic documents. Titles and abstracts of the academic articles were meticulously examined to assess their relevance to the research question. Following this screening process, only 24 academic papers were deemed suitable for deeper examination, providing detailed insights into the theoretical and empirical dimensions of the circular bioeconomy. The grey literature documents, which included policy briefs, government reports, and industry white papers, were similarly scrutinised to ensure alignment with the research objectives. These 14 documents offered practical and contextual insights complementing the academic findings. Figure 2 summarises this process.

The selection followed predefined criteria, focusing on sustainable business models, open innovation, and circular economy challenges in resource-intensive industries. Insights gleaned from this comprehensive review were carefully processed and analysed to establish a foundational understanding of the sector's dynamics and inform subsequent phases of the research.

To ensure the robustness and credibility of the findings, the initial conclusions drawn from the literature review were validated through consultations with subject matter experts. These experts, selected based on their professional experience and academic expertise, provided critical feedback and helped refine the study's focus, ensuring the reliability and accuracy of the derived insights.

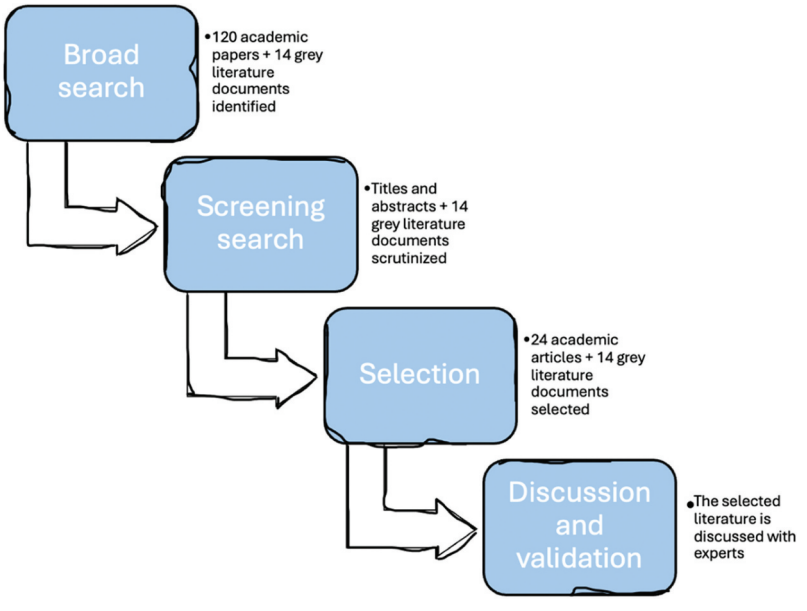


Figure 2. Literature review and academic exploration.

Phase 2: secondary data collection and analysis

Building on the insights gained from the literature review, the second phase focused on collecting and analysing secondary data from a variety of sources to enrich the understanding of the circular bioeconomy within the 4 companies. The secondary data analysed included sustainability reports, website content, material designed to influence public opinion (e.g., corporate social responsibility campaigns), and press releases. Furthermore, pieces from news media, such as interviews with key decision-makers, opinion columns, and industry-focused articles, were included to provide a broader socio-political and economic context.

This comprehensive dataset was processed and analysed to identify meaningful patterns, emerging trends, and underlying themes pertinent to the research objectives. The analysis aimed to uncover how these companies articulate their circular bioeconomy strategies, the narratives they promote, and the stakeholders they engage. Key insights from these sources were organised using coding categories derived from the literature, ensuring a structured and detailed interpretation.

To enhance the reliability of the analytical outcomes, preliminary findings were cross-checked through consultations with subject matter experts. These experts validated the interpretations, offering additional perspectives and addressing any ambiguities that arose during the analysis process. The inclusion of diverse and triangulated data sources strengthened the robustness of this phase, enabling a more nuanced understanding of the practices and challenges faced by the selected companies in transitioning towards a circular bioeconomy. Figure 3 has been elaborated to add clarity to the process of data collection and analysis.

Phase 3: in-depth interviews with decision-makers

The third phase delved into in-depth interviews with key decision-makers across the four companies, ranging from executives such as CEOs, CFOs, COOs, to workers, academics and policymakers associated with the companies. The 24 interviews conducted (see Table 3) lasted between 45 to 90 minutes each. The interviews were recorded, transcribed, and translated from Spanish into English, and underwent a preliminary analysis during data collection to assess saturation and adjust the interview strategy accordingly

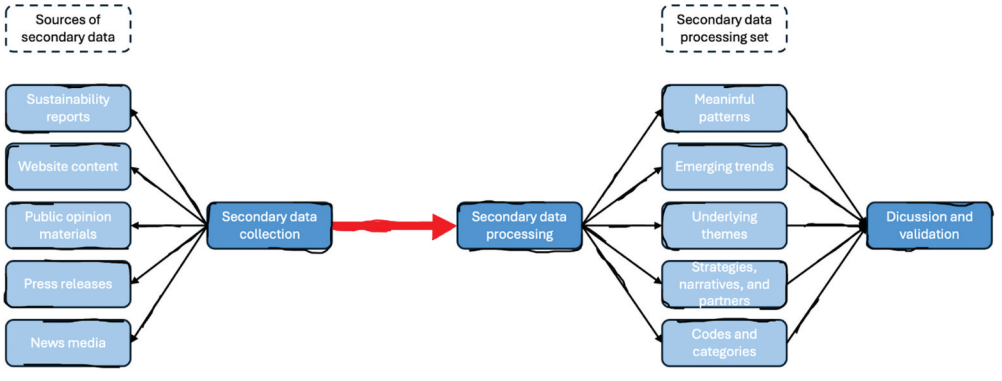


Figure 3. Secondary data collection and analysis.

Table 3. Interviews.

Company A	Company B	Company C	Company D	Other stakeholders
CEO	CEO	CEO	CEO	Academic
COO	COO	CFO	COO	Academic
Logistics Operator	CFO	R&D Manager	Engineer (Design)	Academic
Engineer	Production Manager	Engineer	Engineer (Production)	Policymaker
	R&D Operator	Production Operator		Policymaker
				Policymaker

(Maxwell, 2009). The collected qualitative data underwent thorough processing and analysis, utilising predetermined literature-driven coding categories included the eight business models identified by previous studies (Bocken et al., 2014; D'Amato et al., 2020) and the individual components of the business model: value proposition, value creation and transfer, and value capture (D'Amato et al., 2020). The outcomes were subsequently validated through consultations with specialists, ensuring the reliability and credibility of the identified patterns.

The combination of literature review, secondary data analysis, and in-depth interviews provides a holistic and multi-faceted understanding of the complex dynamics within the circular bioeconomy sector as observed in the four examined companies.

Results

Companies overview

The four companies under consideration assert a strong commitment to sustainable production practices, as evidenced by their displayed international standard certifications that substantiate their dedication to environmentally and socially responsible operations. Viewing sustainability through the lens of the triple bottom line, the top management of these companies articulates diverse initiatives aimed at ensuring profitability while upholding environmental and social responsibilities. For instance, the CEO of Company A underscores,

> the company's long-standing engagement with the local community, by actively participate in social activities and events that garner support from the surrounding population. They love us.

However, critical voices point out the large level of dependency that inhabitants of those communities have developed in relation to the company.

Likewise, the CEO of Company B emphasises the active involvement of their firm in the development of local communities,

> drawing a notable distinction from business models employed by multinational corporations, particularly those operating in free-trade zones, such as the pulp mills alluded to in this context.

Experts agree on the FBB sector's potential for CE and sustainable models, but few companies have achieved closed-loop systems. CEOs of Companies B, C, and D assert that they are actively working towards achieving circularity in their models, acknowledging the existing challenges. In contrast, Company A appears to be lagging, facing

some setbacks in realising a CE. Despite being identified by some interviewees as a potential alternative for improving the implementation of CE and sustainable business models, servitization approaches have not yet been adopted by any of the companies under investigation. For instance, the R&D Manager of Company C asserted that 'In our discussions, we've acknowledged that servitization could play a key role in refining our circular business model. However, it's an area we haven't yet ventured into, though it remains a strategic consideration for future growth'.

In today's digital age, the integration of servitization with digital tools offers unprecedented opportunities for advancing circularity. Technologies such as predictive analytics, IoT, and blockchain could enable these companies to transition towards a service-based model, offering real-time monitoring of resource flows, enhancing transparency, and creating new revenue streams. Yet, the adoption of these technologies remains at a nascent stage, as companies navigate technical and organisational hurdles.

In terms of innovation through collaboration with external stakeholders, there exists a spectrum of experiences. The CEO of Company C highlights their

> commitment to collaboration with various ecosystem partners, particularly research centers and universities, establishing research labs in proximity to knowledge hubs.

Such collaborations have been increasingly underpinned by digital platforms that facilitate remote knowledge exchange, co-creation, and virtual experimentation, enabling partnerships to transcend geographical boundaries. Conversely, Company D operates in a region where human capital and innovation are scarce. According to the COO,

> the company encountered significant challenges in planning production due to a dearth of local knowledge accumulation regarding industrial development. Consequently, critical issues were resolved through internal solutions or consultations with experienced technicians from abroad.

In the digital age, OI platforms could help Company D access global expertise without logistical constraints.

In the following section we address the different business models for both archetypes of sustainability and OI models.

Sustainability archetypes models

The prevailing archetypes identified among the companies include 'Shift to renewables and natural processes', 'Enhancing material and energy efficiency', and 'Embrace stewardship' (Table 3). Conversely, archetypes such as 'Focus on functionality, not ownership' and 'Repurpose for societal/environmental impact' were absent. Varying degrees of adherence to other archetypes, like 'Scale-up solutions', 'Extracting value from waste', and 'Promote sufficiency', were observed.

The analysis of the selected companies reveals a rich tapestry of sustainability practices across multiple archetypal frameworks. Rather than confining each company to a single archetype, this section explores how Companies A, B, C, and D embody overlapping and evolving sustainability strategies (Hansen & Klewitz, 2012).

Company A exemplifies a multifaceted approach to sustainability, particularly 'Embrace Stewardship'. The CEO states,

> The certified quality of our products does not start with the industrial process but with the forestry management. Consequently, our company assures clients across the globe that the material used is part of a certified value chain according to the most rigorous standards of the world.

They also align with the 'Shift to Renewables and Natural Processes' archetype. They utilise forest-based renewable resources and aim to align their products with market trends favouring sustainability. Although this archetype is traditionally associated with improving input-output ratios, Company A integrates it within a broader sustainability framework. As the CEO explains,

> The world is already moving towards these construction forms. Increasingly, new customers are interested not only in comfort and distinguished design but also in the usage of renewable materials that may take them to a more natural experience.

Additionally, Company A integrates 'Enhancing Material and Energy Efficiency'. The COO notes, *'Its environmental value lies in reducing waste and mitigating the over-exploitation of virgin raw materials'*. In alignment with the digital age, Company A has begun exploring digital certification systems and blockchain technology to enhance the traceability of its certified value chains. Such innovations promise to strengthen customer trust while creating a competitive edge in international markets.

Company B reflects the *'Enhancing Material and Energy Efficiency'* archetype. According to the CEO asserts,

> We are committed to using every single inch of the wood that comes into our industrial settlement. There is no such thing as waste in our production process. Left overs are considered energy sources for us.

They also intersect with *'Extracting Value from Waste'*. Beyond using wood waste for energy, Company B's practices include efforts to develop complementary products from remaining raw materials. The CFO notes,

> The company's R&D department has been investigating complementing products that are produced from remaining raw material generated by our production activity. There is an emerging market demanding this kind of outcome.

Leveraging advanced analytics and digital twins, Company B is optimising production processes to achieve near-zero waste. By simulating material flows digitally, the company identifies inefficiencies and enhances energy recovery rates, demonstrating the transformative potential of Industry 4.0 technologies in sustainability efforts.

Company C emphasises *'Promote Sufficiency'* and *'Shift to Renewables and Natural Processes'*. A core element of their approach is the development of durable products designed for long-term use. The CEO explains,

> A main aspect of the environmental policy implied by the firm relies on the fact that we produce goods that are meant to be in the ecosystems for decades and decades. When we think about developing the structure of a whole building, we are assuming that the durability of those materials is a central issue Simultaneously, they utilize forest-based renewable resources and target emerging markets interested in sustainable construction.

The CEO adds,

> Increasingly, new customers are interested not only in comfort and distinguished design but also in the usage of renewable materials that may take them to a more natural experience.

Recognising the importance of data-driven sustainability, Company C has integrated IoT-enabled sensors in its products to monitor their performance over decades. These innovations provide customers with real-time data on product durability and environmental impact, reinforcing the company's commitment to long-term value creation.

Company D focuses on *'Shift to Renewables and Natural Processes' and 'Scale-up Solutions'*. The CEO states,

> Our industrial setting will allow us to rethink the production process backwards, due to it being a source of testing for the quality of the wood we are producing in our forests. In addition, since it is highly probable that other value-adding industries will locate nearby, the outcomes of our factory can easily be considered as an input for the coming industrial venue.

They also demonstrate *'Enhancing Material and Energy Efficiency'*. The company's design focus includes self-sustaining energy systems. The COO explains,

> From the very design of this factory, the company was obsessed with making it self-sustainable in terms of energy production and consumption. Therefore, we produce energy from our waste material, while all the energy that we consume is produced by our own plant.

To further expand its sustainability efforts, Company D is exploring artificial intelligence (AI) tools for predictive maintenance and energy optimisation. These tools help anticipate equipment failures, reduce downtime, and maximise the energy efficiency of their self-sustaining systems.

The cases illustrate that sustainability practices often encompass elements from multiple archetypes rather than fitting neatly into a single category. These case studies reveal that sustainability in the bio-based sector involves a dynamic interplay of archetypal strategies with a range of practices. Incorporating digital technologies into these archetypal models not only enhances their efficiency and impact but also positions companies to meet the demands of an increasingly data-driven global economy. This broader perspective challenges rigid archetypal frameworks and emphasises the need for flexible, integrated approaches to achieving sustainability in the bio-based economy.

Open innovation models

The OI Model by Lazzarotti et al. (2010) provides a structured framework for assessing the level of openness in companies' innovation endeavours. We examine the four companies using two lenses: partners' variety and innovation phases variety. Partners' variety refers to the breadth and diversity of collaborators, while innovation phases variety encompasses the stages within the value chain where innovation is pursued.

Company A, an *'Integrated Collaborator'*, engages extensively in the value chain but limits innovation collaborations. Key partnerships are with institutions like the Uruguayan Technological Laboratory (LATU) and the National Agricultural Research Institute (INIA). The COO states,

> the firm has reached a desirable level of technology that covers the demands of the market segments being attended. At the moment, we are more focused on improving internal

> aspects of the production process and, therefore, there are a few numbers of institutions that we properly trust in this regard.

In terms of innovation phases, Company A plays a vital role in Uruguay's FBB production. It manages significant forestry ventures that supply certified resources to its industrial plant, operating within a structured innovation framework comprising distinct phases. Aligned, the CEO adds,

> Our long track record in this sector has winning us a reputation of consolidate player within the country, this is thank to the fact that we participate in different phases of the whole process.

They show a preference for incorporating established practices rather than spearheading innovation across different stages of the production process. Associated with the digital age, Company A is trying to draw near with other companies in the value chain (clearly company B) and has recently consider the adoption of digital platforms to enhance its collaboration efforts selectively. Following the path of 'Open Innovators' by leveraging digital twins and predictive analytics, it seeks to optimise internal production while exploring limited but high-value partnerships to address targeted challenges. However, the company seems to be far from catching up with the nowadays demands of the digital age top quality production.

Company B, an *'Open Innovator'*, engages extensively with diverse partners and across various innovation phases. The CEO asserts,

> The company has strategically implemented a robust approach that aligns its operations with a wide array of stakeholders spanning the extended forest-based industry. Collaborative efforts extend to farmers, civil society organizations, research institutions such as LATU and INIA, universities, international consultants, auxiliary producers like Beekeepers or livestock producers, and public institutions.

Moreover, in terms of innovation phases, Company B appears as a highly influential participant in Uruguay's FBB. The COO adds, *'this approach has not only created opportunities for innovation but has also positioned the company with a distinctive profile across different production stages'*. Harnessing the power of digital tools, Company B employs cloud-based platforms for stakeholder engagement and real-time data sharing, facilitating seamless collaboration. These technologies also enable the company to integrate external insights rapidly into its innovation processes, enhancing its responsiveness to emerging industry trends.

Company C, a *'Specialized Collaborator'*, shows efforts to integrate OI into its R&D practices but focuses on the industrial production phase. The CEO states,

> This dedication is deeply ingrained in the company's operational framework, fostering connections with a diverse range of partners. These include research centers, universities, design hubs, scientific development units, and various entities within its supply chain, both nationally and internationally.

Concerning innovation phases, the CFO notes, *'Our company places its primary focus on the industrial production phase, specifically centering on the mechanical processing of wood'*. While the range of innovation phases may seem comparatively more specialised than other companies examined in this study, company C stands out as a highly disruptive entity. As such, the R&D Manager adds,

> this firm doesn't just follow trends; we aim to create them. Our R&D efforts focus on breakthroughs that challenge the status quo of the industry. This is part of what we do with our partners. While our approach may appear highly specialized, it's precisely this specialization that allows us to push the boundaries of mechanical processing and set new industry standards. Our goal is not just to innovate but to redefine what's possible in the sector.

To support its disruptive innovation, Company C integrates advanced simulation software and artificial intelligence (AI) into its R&D processes, enabling rapid prototyping and predictive modelling, something absolutely relevant in the housing sector of the digital age. These digital tools help the company test groundbreaking ideas efficiently and accelerate their implementation.

Company D, a *'Closed Innovator'*, emphasises closed practices and relies heavily on internal expertise. The CEO states,

> The company strategically operates a robust R&D unit, acting as a crucial force propelling innovation within the organization. By heavily relying on internal expertise and resources, we aim to streamline our innovation processes, developing exclusive solutions tailored to our specific needs

This closed innovation model grants the company meticulous control over its intellectual property, nurturing a culture centred on confidentiality and the cultivation of exclusive knowledge within its organisational boundaries. According to its COO,

> The company has undergone a substantial evolution, transitioning from its traditional role as a forestry producer to a dynamic industrial player. This transformation introduces diverse stages of innovation, spanning the optimization of forestry practices to the integration of state-of-the-art technologies in the industrial phase. This shift positions the company as a versatile entity engaged in various aspects of the value chain.

To enhance its internal innovation processes, Company D employs secure, in-house digital platforms for R&D collaboration and proprietary data management. These tools allow the company to safeguard its intellectual property while optimising its innovation workflows with advanced machine learning algorithms.

These companies illustrate the varied approaches to OI, from extensive external engagement to focused internal innovation, each tailored to their unique contexts and goals. The integration of digital technologies across these models underscores their transformative potential in shaping OI practices. By enhancing collaboration, optimising production, and safeguarding intellectual property, these technologies are pivotal in adapting OI frameworks to the demands of the digital age.

Integration of sustainability archetypes and open innovation models: an analytical framework

The intersection of sustainability archetypes and OI Models reveals how FBB companies integrate strategies for environmental stewardship and innovation. Companies A, B, C, and D showcase a dynamic spectrum of sustainability strategies, blending multiple archetypes with varied OI models. Company A exemplifies *'Embrace Stewardship'* and *'Shift to Renewables and Natural Processes'*, focusing on certified materials and long-term market trends. The company's value proposition focuses on premium-grade Pine and Eucalyptus sawn timber products for diverse applications both nationally and

internationally. Company A's value creation and transfer strategies include employing renewable resources and improving technological processes to maintain its prestigious market position. Its *'Integrated Collaborator'* OI Model supports established practices through selective partnerships. In the digital age, Company A has begun leveraging advanced analytics and digital monitoring tools to optimise resource efficiency and ensure adherence to global certification standards, further reinforcing its stewardship practices.

In contrast, Company B embraces broad sustainability practices like *'Enhancing Material and Energy Efficiency'* and *'Extracting Value from Waste'*. It represents a broad and inclusive approach to both sustainability and innovation. Its value proposition includes plywood obtained from sustainably managed forests, emphasising both reliability and environmental awareness. As an *'Open Innovator'*, it engages extensively across innovation phases, demonstrating how inclusive OI models drive forward-thinking sustainability. As it has been mentioned before, Company B enhances its collaborative efforts through tools and mechanisms that characterise the current phase of the digital age such as cloud-based innovation platforms and digital supply chain integration, enabling real-time communication with stakeholders and fostering co-creation of sustainable solutions. These digital tools amplify its capacity to meet the growing demand for bio-based eco-friendly products and innovative applications.

Company C specialised innovation efforts intersect with its *'Promote Sufficiency' and 'Shift to Renewables and Natural Processes'* archetypes. The company's value proposition centres around structural housing constructed with Mass Timber, offering an eco-friendly solution with a significant load-bearing capacity. Company C's value creation and transfer strategies include using renewable resources and setting up a regional exemplar for Mass Timber production in South America, aligned with the UN SDGs. The *'Specialized Collaborator'* OI Model facilitates disruptive innovations, emphasising trend-setting R&D efforts in a focused sector. This approach illustrates that specialisation in both sustainability archetypes and OI models can result in transformative impacts and redefinitions of industry standards. By taking advantage of nowadays digital age features, employing digital twins and AI-driven simulations in its R&D, for instance, it is argued that Company C accelerates product development cycles, enhances the durability of its materials, and supports its goal of setting new industry standards in Mass Timber applications.

Company D adopts a *'Closed Innovator'* model, aligning with archetypes such as *'Shift to Renewables and Natural Processes' and 'Scale-up Solutions'*. Its internal R&D capabilities drive deep sustainability efforts and scalable solutions, highlighting the synergy between closed innovation and targeted sustainability strategies. Its value proposition includes wood veneer products made from Eucalyptus Grandis and Pine species for various applications. The company's value creation and transfer strategies involve managing renewable resources, maintaining high employee safety and environmental responsibility, and achieving full energy independence through wood waste utilisation. Incorporating secure, proprietary digital platforms, Company D intends to ensure confidentiality in its innovation processes while utilising machine learning to optimise production workflows and maximise resource use. These digital innovations support the scalability of its sustainability efforts and its energy independence goals, marked by the current phase of the digital age.

These cases show how sustainability archetypes and OI models complement each other, shaping diverse approaches to achieving successful CE implementation and sustainability goals. The comparison between specialised and broad OI models underscores their respective impacts on driving sector-specific innovations versus fostering comprehensive sustainability outcomes. Moreover, the effectiveness of sustainability archetypes is enhanced by specific OI models, reflecting strategic alignment with company objectives and operational contexts. The integration of digital technologies further enhances these synergies, enabling companies to address complex challenges with greater efficiency, agility, and precision. This alignment with the digital age demonstrates how the interplay of sustainability archetypes, OI models, and digital tools is redefining the pathways towards achieving CE and sustainability objectives in the FBB sector.

Discussion

Circular business models components realization in the FBB

The global increase in FBB circularity emphasises its role in substituting virgin inputs with secondary raw materials (ECLAC, 2022). Uruguay's FBB sector exemplifies a trajectory towards a value-added model centred on circularity in the Global South. Our analysis identifies diverse sustainability-focused business archetypes among Uruguayan FBB firms, including *'Shift to renewables and natural processes', 'Enhancing material and energy efficiency', and 'Embrace stewardship'*. The findings indicate that sustainability practices are not confined to a single archetype but instead represent a complex and interrelated set of strategies. By learning from the implementation of these practices in one period, in a subsequent period, firms have the potential to develop their proactive or even frontrunner positioning in the industry even further (Hansen & Klewitz, 2012).

Literature emphasises strategies like closing material loops, while slower adoption of radical circular business models such as sharing models persists (Bocken et al., 2014; D'Amato et al., 2020). Despite recognising servitization's potential for circularity, practices in the case companies show limited exploration in this area, hindering broader business model diversification (Heyes et al., 2018; Urbinati et al., 2023).

The companies' value propositions highlight two key aspects: commitment to sustainable forestry and a focus on international markets. These efforts align with sustainability archetypes like *'Embrace Stewardship' and 'Scale-up Solutions'*, enhancing environmental stewardship and global competitiveness (Boons & Lüdeke-Freund, 2013). As previous works had pointed out, the emphasis on sustainable business models not only meets environmental demands but also enhances corporate reputation and consumer appeal (Boons & Lüdeke-Freund, 2013).

According to the existing literature addressing archetypes of sustainable business, these approaches may illustrate how companies can use sustainability as a strategic asset. Both archetypes *'Embrace Stewardship' and 'Shift to Renewables and Natural Processes'* support the idea that a firm's commitment to sustainability is integral to its value proposition and market position.

Simultaneously, the shared focus on international markets suggests a recognition of the interconnectedness of the global economy and the potential for expanding market

reach. These companies are strategically positioning themselves to tap into diverse consumer bases and capitalise on the increasing demand for timber products worldwide. While engaging in diversification, it also exposes these companies to evolving global standards and preferences. Striking a balance between sustainable practices and international competitiveness becomes crucial (Murray, 1999). In essence, the confluence of sustainable forestry practices and an international market orientation reflects how companies can leverage different sustainability archetypes to achieve both environmental goals and global market success.

Value creation relies on renewable resources and technology, reducing environmental impact, and boosting efficiency. Variations in sustainability methods – from energy efficiency to comprehensive lifecycle approaches – demonstrate diverse paths to environmental and social value creation (Hetemäki, 2015). However, the concrete impact of these ideas on addressing sustainability issues is a topic of considerable discussion (D'Amato & Korhonen, 2021; D'Amato et al., 2017; Kröger & Raitio, 2017).

Strategic engagements in the bioeconomy support cost-effective resource management and revenue diversification, vital for industry growth and sustainability (D'Amato et al., 2020; Reim et al., 2017). However, challenges in profitability remain, particularly in integrating circular strategies and achieving financial sustainability (D'Amato et al., 2020; Ormazabal et al., 2018).

Open innovation models to enhance sustainability in the digital age

Aligned with existing literature, OI models demonstrate how firms leverage internal and external knowledge across innovation stages, shaping and being shaped by sustainability archetypes (Cappa et al., 2022; Franco et al., 2022; Messeni Petruzzelli et al., 2022). Emphasising OI as vital for sustainability-oriented innovation aligns with the need for comprehensive stakeholder engagement to address social and environmental impacts effectively (Hansen & Grosse-Dunker, 2013).

Partnership strategies in the bioeconomy range from extensive collaborations to closed innovation models, reflecting varied approaches to innovation and external collaboration (Lazzarotti et al., 2010; Manzini et al., 2017). Companies balancing internal R&D with external partnerships navigate complex dynamics, ensuring innovation alignment with strategic goals in the FBB sector (Eisenreich et al., 2021; Zangerle et al., 2024).

Furthermore, this integrative perspective encourages collaboration among companies within the FBB value chain. By adopting complementary sustainability practices, firms can strengthen the overall ecosystem's resilience. For example, Company D's scalable solutions and emphasis on renewables create potential synergies with upstream and downstream actors, fostering a CE approach within the sector. Digital platforms and collaborative technologies, such as cloud-based resource sharing and predictive analytics for supply chain optimisation, further enhance these synergies, enabling more effective and seamless interactions across the value chain.

The dynamic characteristic of the sustainable business archetypes

Building on the findings already discussed, the notion of sustainability as a dynamic and overlapping set of approaches introduces important strategic implications for FBB

companies. Instead of fixed models, companies can see sustainability as a flexible strategy adapting to market and regulatory shifts. This flexibility is crucial, particularly in sectors like the FBB, where the interplay between environmental, economic, and social factors is complex and context-specific.

For instance, by not being confined to a single archetype, companies can tailor their sustainability strategies to exploit specific advantages in their value chain. Company A's emphasis on stewardship and renewables positions it strongly in markets with high demand for certified, eco-friendly products, while Company B's focus on waste valorisation and efficiency enables operational cost savings and diversifies its product portfolio. These overlapping strategies also create opportunities for cross-learning and innovation within the sector, as companies can draw from multiple archetypes to enhance their competitive positioning. Digital tools like AI-driven analysis and blockchain certification help companies adapt strategies while ensuring transparency and stakeholder trust.

Ultimately, recognising sustainability strategies as fluid rather than fixed archetypes aligns well with the complexities of the digital age (Alcayaga et al., 2019). It empowers FBB companies to remain agile and innovative while meeting the dual goals of environmental stewardship and economic growth. Digital solutions improve transparency, stakeholder engagement, and scalability, strengthening FBB sustainability strategies. The bioeconomy can add societal and environmental value, but rigorous verification is needed to mitigate rebound effects and regional disparities (Bruno et al., 2023). This research suggests that aligning circular bioeconomy principles with broader sustainability frameworks like the green economy and SDGs remains essential for achieving long-term societal and environmental benefits (Chiaroni et al., 2022; D'Amato & Korhonen, 2021).

From a managerial standpoint, understanding sustainability as a flexible and overlapping spectrum of practices underscores the importance of fostering organisational cultures that prioritise adaptability and long-term planning. Managers are encouraged to evaluate sustainability not just as a set of static targets but as an ongoing, iterative process that evolves in response to internal capabilities and external pressures - which can lead to progressively advancing strategic positioning of companies towards sustainability (Hansen & Klewitz, 2012). The digital age amplifies this adaptability, with tools like digital twins and IoT-enabled monitoring systems providing managers with real-time insights into operational performance and sustainability metrics. These innovations empower leaders to make data-driven decisions, ensuring that sustainability remains an integral part of their organisations' strategic focus.

In sum, FBB circularity and sustainability archetypes define a dynamic spectrum in the bioeconomy. OI Models and strategic engagements underscore the pivotal role of innovation and stakeholder collaboration in achieving sustainable growth and market success.

Implications and conclusion

Scientific implications

The findings provide a valuable framework for advancing the scientific understanding of circularity in the FBB sector by integrating sustainability-focused business models

archetypes with OI models. This research highlights the interplay between technological advancements, OI, and sustainability, demonstrating the need for interdisciplinary approaches to tackle CE implementation challenges. This study highlights how sustainability archetypes evolve over time, inviting further research on their market and regulatory interactions.

Moreover, the integration of digital tools, such as blockchain and AI, presents an opportunity to deepen academic inquiry into their role in fostering transparency and traceability in circular systems. The servitization trend discussed offers a promising area for further exploration into how digital eco-design innovations can reshape product life cycles and customer relationships. Investigating the scalability of these solutions across regions, especially in the Global South, could provide critical insights into the mechanisms for transferring knowledge and technology between contexts. Additionally, the relationship between OI models and the development of bio-based materials warrants further scientific exploration to understand how collaborative ecosystems can optimise resource efficiency and sustainability.

This research also underscores the importance of understanding how companies balance open and closed innovation strategies in the FBB sector, paving the way for comparative studies across different industries and geographical contexts. Such investigations could contribute to developing predictive models for innovation pathways, guiding policymakers and industry leaders in prioritising investments and resources. Furthermore, the study highlights the need for systematic evaluations of digital transformation's environmental impacts, offering a basis for future work on quantifying the net benefits of CE implementation in the FBB and beyond.

Managerial implications

Managers in the FBB should recognise the importance of aligning their business models with sustainability, as evidenced by the commitment to sustainable forestry practices among the analysed companies. Emphasising renewable resources, embracing technological advancements, and engaging in international markets contribute to long-term viability and competitiveness. Companies can benefit from a nuanced approach that balances energy efficiency, environmental responsibility, and safety considerations.

Specific strategies arise from this study's findings. For instance, managers of companies aligned with the 'Shift to Renewables and Natural Processes' archetype could better integrate agroforestry practices into their operations, enhancing biodiversity and soil health while diversifying revenue streams through ecosystem services. Firms emphasising 'Enhancing Material and Energy Efficiency' may consider adopting advanced digital twins to simulate and optimise production processes, minimising material waste and energy use across the supply chain. AI-driven predictive maintenance and IoT sensors in sawmills improve efficiency, cut energy use, and boost yield accuracy.

Companies following the 'Promote Sufficiency' archetype could create modular, prefabricated timber components for construction projects, allowing clients to customise solutions while reducing waste. These efforts can be supported by digital design platforms and 3D printing technologies, which enable precise production and reduce material surplus. By embedding circularity principles into these designs, they can appeal to global markets increasingly favouring sustainable building materials. Managers

adopting OI models should forge partnerships with technological startups specialising in bio-based adhesives or nanotechnology for wood coatings to enhance product durability and sustainability. Closed innovation strategies, in turn, could focus on in-house R&D programs to develop proprietary, low-carbon pyrolysis techniques for processing wood waste into high-value biochar or renewable energy.

The varying partnering strategies, from OI to closed models, highlight the need for managers to carefully consider their innovation approach. Companies opting for OI should actively seek collaborations with diverse stakeholders, recognising the value of external expertise in driving innovation. In contrast, those adopting closed innovation models should emphasise internal R&D capabilities to maintain control over intellectual property. Managers must also leverage digital ecosystems to foster collaboration, using platforms that integrate partners across the value chain and enhance knowledge-sharing through real-time data access and AI-based insights.

Policy implications

Policymakers can support the FBB by promoting sustainability initiatives and incentivising companies to adopt circular business models. For example, offering fiscal incentives for companies investing in carbon-neutral production technologies or renewable energy systems could accelerate sector-wide adoption of these practices. Moreover, subsidies for exporting high-value, certified sustainable timber products would enhance the competitiveness of FBB firms in international markets. Policies that promote digital transformation, such as tax credits for adopting Industry 4.0 technologies or grants for developing AI-driven sustainability solutions, can further strengthen the sector's innovation capacity. Encouraging research partnerships through targeted grants, particularly in collaboration with universities or international organisations, can help generate cutting-edge solutions to longstanding challenges, such as low-grade residue valorisation.

A better coordination among state agencies such as the National Development Agency (ANDE), the National Agency for Research and Innovation (ANII), the newly created Innovation Hub, the National Institute of Agricultural Research (INIA), and related Ministries is highly encouraged. Such inter-agency collaboration can facilitate the creation of integral policies that combine economic incentives, technological support, and regulatory frameworks. Integrating digital governance tools, such as centralised data platforms and AI-based policy monitoring systems, could enhance coordination and ensure that initiatives are effectively aligned with sustainability goals. For example, ANII could deeper into funding R&D projects focusing on sustainable forestry innovations, while the Ministry of Industry, Energy, and Mining (MIEM), and the ANDE provides financial backing for scaling these innovations in the market. INIA has to complement this effort by reinforcing the development of guidelines for agroforestry practices, ensuring that land use strategies align with environmental and production goals. Coordinating these efforts under a unified strategy would amplify their impact.

Encouraging collaboration with research institutions, fostering international partnerships, and providing resources for technological advancements can enhance the sector's overall competitiveness. Policymakers should also consider the global interconnectedness of the industry, ensuring that regulations align with international standards while promoting sustainable practices.

Concluding remarks

The global rise in the circularity of the FBB emphasises its potential to replace virgin inputs with secondary raw materials on a global scale. The bioeconomy research context offers a compelling case for the transition towards a more value-added development model with a focus on circularity. The analysis of sustainability-focused business models among Uruguayan FBB companies reveals key archetypes, highlighting the sector's emphasis on renewables, enhanced material efficiency, and environmental stewardship in the Global South. In the digital age, these strategies gain further relevance as advanced technologies facilitate more precise tracking of material flows, enable innovative production techniques, and enhance transparency through digital certification systems, such as blockchain-based traceability. The results demonstrate that, in the digital age, sustainability practices are best understood as a dynamic and overlapping spectrum of strategies rather than fixed archetypes. It can be categorised as a sort of continuity rather than anchored models. Likewise, OI models offer insights into how companies harness external and internal knowledge throughout diverse innovation stages. Digital platforms, such as collaborative innovation hubs and AI-driven data analytics, play a critical role in streamlining these models by fostering connections among stakeholders and identifying novel opportunities for value creation. By combining these viewpoints, it becomes clear that the choice of sustainability archetypes often affects and is affected by the companies' OI models. The servitization megatrend emerges as a pathway to diversify the FBB, supporting a shift from a product-oriented to a user-centred eco-design. This shift is increasingly driven by digital tools that enable mass customisation, predictive maintenance, and product-as-a-service offerings, transforming traditional value chains into integrated ecosystems. Sustainable forestry practices and an orientation towards international markets are identified as defining characteristics, shaping the strategic positioning of companies in the FBB sector.

Commonalities across companies include a commitment to sustainable practices, a focus on renewable resources, and continuous technological improvement. While there is a shared dedication to sustainability, companies exhibit divergent approaches, with some emphasising energy efficiency and others adopting a holistic approach from planting to the industrial phase. The adoption of Industry 4.0 technologies, such as IoT-enabled sensors and automated quality control systems, further supports these efforts by providing real-time insights and reducing inefficiencies. The confluence of sustainable forestry practices and an international market orientation strategically positions companies globally.

The FBB presents significant opportunities for sustainable development, and managerial and policy decisions play pivotal roles in shaping its trajectory. By embracing the digital age and leveraging advanced technologies, the sector can achieve greater agility, transparency, and innovation, ensuring it remains a cornerstone of sustainable economic growth. Balancing environmental stewardship, technological innovation, and international competitiveness will be key to unlocking the full potential of the sector.

In conclusion, the digital age is profoundly transforming both OI and sustainability strategies within FBB companies, enabling new forms of collaboration, efficiency, and transparency. Digital platforms facilitate multi-stakeholder engagement by connecting firms with research institutions, startups, and policymakers, accelerating knowledge

exchange and innovation. For instance, AI-driven analytics and big data enhance decision-making processes by providing real-time insights into supply chain sustainability, resource efficiency, and market trends. Blockchain-based certification systems further reinforce transparency, ensuring traceability of raw materials and compliance with sustainability standards. These digital tools not only improve operational efficiency but also expand the scope of OI by lowering barriers to collaboration, allowing firms to integrate external expertise while maintaining competitive advantages.

Moreover, digitalisation enhances circular implementation in the FBB sector by enabling more precise resource management and fostering servitization strategies. IoT-enabled sensors and digital twins optimise material flows, reduce waste, and support predictive maintenance, increasing the lifespan of bio-based products. Digital eco-design tools, such as 3D modelling and lifecycle assessment software, facilitate the development of sustainable products by minimising environmental impact from the design phase. These advancements align with OI principles by promoting open data-sharing and co-creation among stakeholders, ultimately strengthening the sector's transition towards circularity. By embedding digitalisation into sustainability and OI strategies, FBB companies can enhance resilience, scalability, and long-term competitiveness in an increasingly interconnected and resource-constrained world.

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References

Alblas, A., & Wortmann, H. (2009, August 24–27). The need for function platforms in engineer-to-order industries. *Proceedings of the 17th international conference on engineering design (ICED2009)*, Palo Alto, CA.

Alcayaga, A., & Hansen, E. G. (2025). Smart circular economy as a service business model: An activity system framework and research agenda. *R&D Management*, *55*(2), 508–530. https://doi.org/10.1111/radm.12707

Alcayaga, A., Wiener, M., & Hansen, E. G. (2019). Towards a framework of smart-circular systems: An integrative literature review. *Journal of Cleaner Production*, *221*, 622–634. https://doi.org/10.1016/j.jclepro.2019.02.085

Ali, A., Mahfouz, A., & Arisha, A. (2017). Analysing supply chain resilience: Integrating the constructs in a concept mapping framework via a systematic literature review. *Supply Chain Management: An International Journal*, *22*(1), 16–39. https://doi.org/10.1108/SCM-06-2016-0197

Angelshaug, M. S., Saebi, T., Lien, L., & Foss, N. J. (2023). Searching wide and deep for business model innovation. *Innovation*, 1–24. https://doi.org/10.1080/14479338.2023.2252789

Antikainen, R., Dalhammar, C., Hildén, M., Judl, J., Jääskeläinen, T., Kautto, P., Koskela, S., Kuisma, M., Lazarevic, D., & Mäenpää, I. (2017). Renewal of forest based manufacturing towards a sustainable circular bioeconomy. *Reports of the Finnish Environment Institute*.

Bezama, A. (2016). Let us discuss how cascading can help implement the circular economy and the bio-economy strategies. *Waste Management & Research: The Journal for a Sustainable Circular Economy*, *34*(7), 593–594. https://doi.org/10.1177/0734242X16657973

Bocken, N. M. P., Short, S. W., Rana, P., & Evans, S. (2014). A literature and practice review to develop sustainable business model archetypes. *Journal of Cleaner Production*, *65*, 42–56. https://doi.org/10.1016/j.jclepro.2013.11.039

Bombeck, P.-L., Khatri, V., Meddeb-Mouelhi, F., Montplaisir, D., Richel, A., & Beauregard, M. (2017). Predicting the most appropriate wood biomass for selected industrial applications: Comparison of wood, pulping, and enzymatic treatments using fluorescent-tagged carbohydrate-binding modules. *Biotechnology for Biofuels*, *10*(1), 293. https://doi.org/10.1186/s13068-017-0980-0

Boons, F., & Lüdeke-Freund, F. (2013). Business models for sustainable innovation: State-of-the-art and steps towards a research agenda. *Journal of Cleaner Production*, *45*, 9–19. https://doi.org/10.1016/j.jclepro.2012.07.007

Boyer, K. K., Swink, M., & Rosenzweig, E. D. (2009). Operations strategy research in the POMS journal. *Production & Operations Management*, *14*(4), 442–449. https://doi.org/10.1111/j.1937-5956.2005.tb00232.x

Bruno, M. P., Cendón, M. L., & Viteri, M. L. (2023). Territorial add value strategies: Circular bioeconomy experiences from Balcarce (Argentina). *Revista Iberoamericana de Viticultura Agroindustria y Ruralidad*, *10*(28), 58–76. https://doi.org/10.35588/rivar.v10i28.5339

Cappa, F., Franco, S., & Rosso, F. (2022). Citizens and cities: Leveraging citizen science and big data for sustainable urban development. *Business Strategy and the Environment*, *31*(2), 648–667. https://doi.org/10.1002/bse.2942

Cappa, F., Oriani, R., Pinelli, M., & De Massis, A. (2019). When does crowdsourcing benefit firm stock market performance? *Research Policy*, *48*(9), 103825. https://doi.org/10.1016/j.respol.2019.103825

Carus, M., & Dammer, L. (2018). The circular bioeconomy—concepts, opportunities, and limitations. *Industrial Biotechnology*, *14*(2), 83–91. https://doi.org/10.1089/ind.2018.29121.mca

Chesbrough, H. (2006). Open innovation: A new paradigm for understanding industrial innovation. In H. Chesbrough, W. Vanhaverbeke, & J. West (Eds.), *Open innovation: Researching a new paradigm* (p. 27). Oxford University Press.

Chiaroni, D., Fraccascia, L., Giannoccaro, I., & Urbinati, A. (2022). Enabling factors for the diffusion of circular economy and their impacts on sustainability. *Resources, Conservation and Recycling Advances*, *15*, 15. https://doi.org/10.1016/j.rcradv.2022.200101

Ciccarese, L., Pellegrino, P., & Pettenella, D. (2014). A new principle of the European Union forest policy: The cascading use of wood products. *L'Italia forestale e montana*, 285–290. https://doi.org/10.4129/ifm.2014.5.01

Colicchia, C., Creazza, A., Noè, C., & Strozzi, F. (2019). Information sharing in supply chains: A review of risks and opportunities using the systematic literature network analysis (SLNA). *Supply Chain Management: An International Journal*, *24*(1), 5–21. https://doi.org/10.1108/SCM-01-2018-0003

Colicchia, C., & Strozzi, F. (2012). Supply chain risk management: A new methodology for a systematic literature review. *Supply Chain Management: An International Journal*, *17*(4), Article 4. 403–418. https://doi.org/10.1108/13598541211246558

Creswell, J. W., & Poth, C. N. (2016). *Qualitative inquiry and research design: Choosing among five approaches*. SAGE Publications.

D'Amato, D., Droste, N., Allen, B., Kettunen, M., Lähtinen, K., Korhonen, J., Leskinen, P., Matthies, B. D., & Toppinen, A. (2017). Green, circular, bio economy: A comparative analysis of sustainability avenues. *Journal of Cleaner Production*, *168*, 716–734. https://doi.org/10.1016/j.jclepro.2017.09.053

D'Amato, D., & Korhonen, J. (2021). Integrating the green economy, circular economy and bioeconomy in a strategic sustainability framework. *Ecological Economics*, *188*, 107143. https://doi.org/10.1016/j.ecolecon.2021.107143

D'Amato, D., Veijonaho, S., & Toppinen, A. (2020). Towards sustainability? forest-based circular bioeconomy business models in Finnish SMEs. *Forest Policy and Economics*, *110*, 110. https://doi.org/10.1016/j.forpol.2018.12.004

DaSilva, C. M., & Trkman, P. (2014). Business Model: What it is and what it is not. *Long Range Planning*, *47*(6), 379–389. https://doi.org/10.1016/j.lrp.2013.08.004

De Corato, U., De Bari, I., Viola, E., & Pugliese, M. (2018). Assessing the main opportunities of integrated biorefining from agro-bioenergy co/by-products and agroindustrial residues into high-value added products associated to some emerging markets: A review. *Renewable and Sustainable Energy Reviews*, *88*, 326–346. https://doi.org/10.1016/j.rser.2018.02.041

Denyer, D., & Tranfield, D. (2009). Producing a systematic review. In *The sage handbook of organizational research methods* (pp. 671–689). Sage.

Dieste, A., Baño, V., Cabrera, M. N., Clavijo, L., Palombo, V., Moltini, G., & Cassella, F. (2021). The potential of Uruguay within the global expansion of wood construction. *WCTE*. World Conference on Timber Engineering 2021, WCTE 2021. https://www.scopus.com/inward/record.uri?eid=2-s2.0-85120745684&partnerID=40&md5=04de6bb3a023173f25f4414f50820424

Dieste, A., Cabrera, M. N., Clavijo, L., & Cassella, N. (2019). Analysis of wood products from an added value perspective: The Uruguayan forestry case. *Maderas Ciencia y tecnología*, *21*(ahead), 305–316. https://doi.org/10.4067/S0718-221X2019005000303

Dorrego, J. I., Lazzarotti, V., & Collazzo, P. (2024). Supply chain and open innovation: The undeniable relationship conceptions from a literature review. *Empresa y Sociedad*, *4*, 11–26. https://doi.org/10.5377/emyso.v4i1.18384

Dorrego-Viera, J. I., Santolin, R. B., Lazzarotti, V., & Urbinati, A. (2023). Sustainability decision-making in times of crisis: An empirical study in Italy under the lens of the Russian-Ukraine war. *Corporate Social Responsibility & Environmental Management*, *31*(5), 3988–4006. https://doi.org/10.1002/csr.2788

Dorrego-Viera, J., Urbinati, A., & Lazzarotti, V. (2025). Transition towards circular economy: Exploiting open innovation for circular product development. *Journal of Innovation & Knowledge*, *10*(2), 2. https://doi.org/10.1016/j.jik.2025.100668

Dossa, K. F., & Miassi, Y. E. (2024, December). Urban planning and green infrastructure under a changing climate in Africa. *International Journal of Regional Development, Macrothink Institute*, *11*(1), 1–1.

ECLAC. (2022). *INTERNATIONAL TRADE OUTLOOK for LATIN AMERICA and the CARIBBEAN 2021: Pursuing a resilient and. . . sustainable recovery*. UNITED NATIONS.

Eisenhardt, K. M., & Graebner, M. E. (2007). Theory building from cases: Opportunities and challenges. *Academy of Management Journal*, *50*(1), 25–32. https://doi.org/10.5465/amj.2007.24160888

Eisenreich, A., Füller, J., & Stuchtey, M. (2021). Open circular innovation: How companies can develop circular innovations in collaboration with stakeholders. *Sustainability (Switzerland)*, *13*(23), 13456. https://doi.org/10.3390/su132313456

Foundation, E. M. (2013). *Towards the circular economy: Economic and business rationale for accelerated transition*. Ellen MacArthur Foundation.

Fraccascia, L., Giannoccaro, I., Abhishek, A., & Hansen, E. G. (2021). Business models for the circular economy: Empirical advances and future directions. *Business Strategy and the Environment*, *30*(6), 2741–2744. https://doi.org/10.1002/bse.2896

Franco, S., Presenza, A., & Petruzzelli, A. M. (2022). Boosting innovative business ideas through hackathons. The "hack for travel" case study. *European Journal of Innovation Management*, *25*(6), 413–431. https://doi.org/10.1108/EJIM-06-2021-0300

Gawer, A. (2022). Digital platforms and ecosystems: Remarks on the dominant organizational forms of the digital age. *Innovation*, *24*(1), 110–124. https://doi.org/10.1080/14479338.2021.1965888

Gummesson, E. (1991). "Qualitative research in management." *Qualitative methods in management research*. Sage Publications.

Gustafsson J. (2017). *Single case studies vs. Multiple case studies: A comparative study*.Academy of Business, Engineering and Science Halmstad University.

Hansen, E. G., & Grosse-Dunker, F. (2013). Sustainability-oriented innovation. In S. O. Idowu, N. Capaldi, L. Zu, & A. D. Gupta (Eds.), *Encyclopedia of corporate social responsibility: Heidelberg, Germany* (Vol. 4, pp. 2407–2417). Springer. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=2191679

Hansen, E. G., Grosse-Dunker, F., & Reichwald, R. (2009). Sustainability innovation cube: A framework to evaluate sustainability of product innovations. *XX ISPIM Conference*, Vienna, Austria.

Hansen, E. G., & Klewitz, J. (2012). The role of an SME's green strategy in public-private eco-innovation initiatives: The case of ecoprofit. *Journal of Small Business & Entrepreneurship*, *25* (4), 451–477. https://doi.org/10.1080/08276331.2012.10593584

Hansen, E. G., & Revellio, F. (2020). Circular value creation architectures: Make, ally, buy, or laissez-faire. *Journal of Industrial Ecology*, *24*(6), 1250–1273. https://doi.org/10.1111/jiec.13016

Hansen, E. G., & Schmitt, J. C. (2021). Orchestrating cradle-to-cradle innovation across the value chain: Overcoming barriers through innovation communities, collaboration mechanisms, and intermediation. *Journal of Industrial Ecology*, *25*(3), 627–647. https://doi.org/10.1111/jiec.13081

Hetemäki, L. (2015). Future of European Forest-based sector. *Presentation at the German Forestry Association (Deutschen Forstvereins)*, Flensburg. https://doi.org/10.13140/RG.2.1.3775.9844

Heyes, G., Sharmina, M., Mendoza, J. M. F., Gallego-Schmid, A., & Azapagic, A. (2018). Developing and implementing circular economy business models in service-oriented technology companies. *Journal of Cleaner Production*, *177*, 621–632. https://doi.org/10.1016/j.jclepro.2017.12.168

IEA. (2023). *World energy outlook*. International Energy Agency. https://www.iea.org/

Kefeli, D., Siegel, K. M., Pittaluga, L., & Dietz, T. (2023). Environmental policy integration in a newly established natural resource-based sector: The role of advocacy coalitions and contrasting conceptions of sustainability. *Policy Sciences*, *56*(1), 69–93. https://doi.org/10.1007/s11077-022-09485-z

Kembro, J., Selviaridis, K., & Näslund, D. (2014). Theoretical perspectives on information sharing in supply chains: A systematic literature review and conceptual framework. *Supply Chain Management: An International Journal*, *19*(5/6), 609–625. https://doi.org/10.1108/SCM-12-2013-0460

Kirchherr, J., Reike, D., & Hekkert, M. (2017). Conceptualizing the circular economy: An analysis of 114 definitions. *Resources, Conservation & Recycling*, *127*, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Korhonen, J., Honkasalo, A., & Seppälä, J. (2018). Circular economy: The concept and its limitations. *Ecological Economics*, *143*, 37–46. https://doi.org/10.1016/j.ecolecon.2017.06.041

Kröger, M., & Raitio, K. (2017). Finnish forest policy in the era of bioeconomy: A pathway to sustainability? *Forest Policy and Economics*, *77*, 6–15. https://doi.org/10.1016/j.forpol.2016.12.003

Kvale, S., & Brinkmann, S. (2009). *InterViews: Learning the craft of qualitative research interviewing*. Sage Publications.

Lazzarotti, V., Manzini, R., & Pellegrini, L. (2010). Open innovation models adopted in practice: An extensive study in Italy. *Measuring Business Excellence*, *14*(4), 11–23. https://doi.org/10.1108/13683041011093721

Lowe, B. H., Bimpizas-Pinis, M., Zerbino, P., & Genovese, A. (2024). Methods to estimate the circular economy rebound effect: A review. *Journal of Cleaner Production*, *443*, 141063. https://doi.org/10.1016/j.jclepro.2024.141063

Manzini, R., Lazzarotti, V., & Pellegrini, L. (2017). How to remain as closed as possible in the open innovation Era: The case of Lindt & sprüngli. *Long Range Planning*, *50*(2), 260–281. https://doi.org/10.1016/j.lrp.2015.12.011

Maxwell, J. A. (2009). Designing a qualitative study. *The SAGE Handbook of Applied Social Research Methods*, *2*(7), 214–253.

Messeni Petruzzelli, A., Murgia, G., & Parmentola, A. (2022). How can open innovation support SMEs in the adoption of I4.0 technologies? An empirical analysis. *R & D Management*, *52*(4), 615–632. https://doi.org/10.1111/radm.12507

Mintzberg, H. (1979). An emerging strategy of "direct" research. *Administrative Science Quarterly*, *24*(4), 582. https://doi.org/10.2307/2392364

Mongeon, P., & Paul-Hus, A. (2016). The journal coverage of Web of Science and Scopus: A comparative analysis. *Scientometrics*, *106*(1), Article 1. 213–228. https://doi.org/10.1007/s11192-015-1765-5

Murray, A. T. (1999). *Spatial restrictions in harvest scheduling. Forest Science*. https://www.semanticscholar.org/paper/Spatial-restrictions-in-harvest-scheduling-Murray/83e2baa279e3ee6774f7649b2e4a845b86ff40e8

Näyhä, A. (2019). Transition in the Finnish forest-based sector: Company perspectives on the bioeconomy, circular economy and sustainability. *Journal of Cleaner Production*, *209*, 1294–1306. https://doi.org/10.1016/j.jclepro.2018.10.260

Oficina de Planeamiento y Presupuesto. (2019a). *Aportes para una estrategia de desarrollo 2050*. Oficina de Planeamiento y Presupuesto.

Oficina de Planeamiento y Presupuesto. (2019b). Oportunidades para el futuro de la bioeconomía forestal en Uruguay. *Hacia una Estrategia Nacional de Desarrollo, Uruguay 2050 Serie de divulgación - Volumen XII Dirección de Planificación Oficina de Planeamiento y Presupuesto*.

Ormazabal, M., Prieto-Sandoval, V., Puga-Leal, R., & Jaca, C. (2018). Circular economy in Spanish SMEs: Challenges and opportunities. *Journal of Cleaner Production*, *185*, 157–167. https://doi.org/10.1016/j.jclepro.2018.03.031

Osterwalder, A., Pigneur, Y., & Tucci, C. L. (2005). Clarifying business models: Origins, present, and future of the concept. *Communications of the Association for Information Systems*, *16*. https://doi.org/10.17705/1CAIS.01601

Popper, R., Rilla, N., Niemelä, K., Oksanen, J., Deschryvere, M., Virkkunen, M., & Loikkanen, T. (2020). *The future of forest-based bioeconomy areas*. VTT Technical Research Centre of Finland. https://doi.org/10.32040/2242-122X.2020.T379

Reim, W., Sjödin, D., Parida, V., Rova, U., & Christakopoulos, P. (2017). Bio-economy based business models for the forest sector-A systematic literature review. *International Scientific Conference RURAL DEVELOPMENT 2017* (pp. 775–780.

Richardson, J. (2008). The business Model: An integrative framework for strategy execution. *Strategic Change*, *17*(5–6), 133–144. https://doi.org/10.1002/jsc.821

Salvador, R., Barros, M. V., Donner, M., Brito, P., Halog, A., & De Francisco, A. C. (2022). How to advance regional circular bioeconomy systems? Identifying barriers, challenges, drivers, and opportunities. *Sustainable Production and Consumption*, *32*, 248–269. https://doi.org/10.1016/j.spc.2022.04.025

Salvador, R., Barros, M. V., Pieroni, M., Lopes Silva, D. A., Freire, F., & De Francisco, A. C. (2023). Overarching business models for a circular bioeconomy: Systematising archetypes. *Sustainable Production and Consumption*, *43*, 349–362. https://doi.org/10.1016/j.spc.2023.11.010

Sassanelli, C., Rosa, P., Rocca, R., & Terzi, S. (2019). Circular economy performance assessment methods: A systematic literature review. *Journal of Cleaner Production*, *229*, 440–453. https://doi.org/10.1016/j.jclepro.2019.05.019

Schaltegger, S., Lüdeke-Freund, F., & Hansen, E. G. (2012). Business cases for sustainability: The role of business model innovation for corporate sustainability. *International Journal of Innovation and Sustainable Development*, *6*(2), 95–119. https://doi.org/10.1504/IJISD.2012.046944

Schaltegger, S., Lüdeke-Freund, F., & Hansen, E. G. (2016). Business models for sustainability: A Co-evolutionary analysis of sustainable entrepreneurship, innovation, and transformation. *Organization & Environment*, *29*(3), 264–289. https://doi.org/10.1177/1086026616633272

Stake, R. E. (2013). *Multiple case study analysis*. Guilford Press.

Teece, D. J. (2010). Business models, business strategy and innovation. *Long Range Planning*, *43* (2–3), 172–194. https://doi.org/10.1016/j.lrp.2009.07.003

Urbinati, A., Franzò, S., & Chiaroni, D. (2021). Enablers and barriers for circular business models: An empirical analysis in the Italian automotive industry. *Sustainable Production and Consumption*, *27*, 551–566. https://doi.org/10.1016/j.spc.2021.01.022

Urbinati, A., Manelli, L., Frattini, F., & Bogers, M. L. A. M. (2022). The digital transformation of the innovation process: Orchestration mechanisms and future research directions. *Innovation*, *24*(1), 65–85. https://doi.org/10.1080/14479338.2021.1963736

Urbinati, A., Rosa, P., Sassanelli, C., Chiaroni, D., & Terzi, S. (2020). Circular business models in the European manufacturing industry: A multiple case study analysis. *Journal of Cleaner Production*, *274*, 122964. https://doi.org/10.1016/j.jclepro.2020.122964

Urbinati, A., Shams Esfandabadi, Z., & Messeni Petruzzelli, A. (2023). Assessing the interplay between open innovation and Sustainability-oriented innovation: A systematic literature review and a research agenda. *Business Ethics, the Environment and Responsibility*, *32*(3), 1078–1095. https://doi.org/10.1111/beer.12540

Velenturf, A. P., & Purnell, P. (2021). Principles for a sustainable circular economy. *Sustainable Production and Consumption*, *27*, 1437–1457. https://doi.org/10.1016/j.spc.2021.02.018

Weiss, M., Haufe, J., Carus, M., Brandão, M., Bringezu, S., Hermann, B., & Patel, M. K. (2012). A review of the environmental impacts of biobased materials. *Journal of Industrial Ecology*, *16*(1), S169–S181. https://doi.org/10.1111/j.1530-9290.2012.00468.x

Yin, R. K. (2009). *Case study research: Design and methods* (4th ed. Vol. 5). Sage.

Zangerle, K., Dobusch, L., & Weiskopf, R. (2024). Barracudas, piranhas and crowds: Making ideas valuable in pharmaceutical innovation through opening and closing practices of valuation. *Innovation*, 1–18. https://doi.org/10.1080/14479338.2024.2339257

Zerbino, P. (2022). How to manage the circular economy rebound effect: A proposal for contingency-based guidelines. *Journal of Cleaner Production*, *378*, 134584. https://doi.org/10.1016/j.jclepro.2022.134584

Zhu, J., & Liu, W. (2020). A tale of two databases: The use of Web of Science and Scopus in academic papers. *Scientometrics*, *123*(1), 321–335. https://doi.org/10.1007/s11192-020-03387-8