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Sustainable Scaling in Forest-Based Circular Models

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Abstract

The transition to a circular economy is essential for enhancing sustainability and resource efficiency, particularly in forestry-dependent regions. This study examines circular economy business models (CEBMs) in Kouvola, Finland, focusing on the utilization of forestry by-products. It compares two case studies: Keltakangas Waste Station, which processes wood waste into biogas, and Koumet, a forestry company producing biochar. Using a comparative case study approach, this research integrates financial analysis (2020–2023), interviews with managers, and policy reviews to assess economic performance, scalability, and environmental impact. Additionally, this study introduces a generalizable framework—Scalability Path Dependency (SPD)—which theorizes how early strategic decisions shape the long-term growth trajectories of circular business models. The findings reveal that Keltakangas follows a capital-intensive model with declining profit margins, while Koumet operates a resource-efficient model with stable but low profitability. Their scaling strategies diverge: Keltakangas relies on external financing for expansion, whereas Koumet emphasizes cost efficiency and market diversification. Despite ongoing challenges related to infrastructure, regulation, and financial viability, both models contribute meaningfully to circularity. This study offers actionable insights for policymakers and businesses aiming to support sustainable forestry practices.

Keywords: circular economy business models; sustainability; scalability; forestry by-products

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1. Introduction

Kouvola, located in southeastern Finland near the Russian border, is a pivotal city in the Kymenlaakso region. Situated about 130 km northeast of Helsinki, it is strategically positioned along key rail and road routes that connect Finland to Russia, making it an essential transit hub for regional trade. Notably, Kouvola is Finland's most forest-rich area, with forests covering approximately 70% of its land. These forests, dominated by pine, spruce, and birch, are crucial to the region's thriving wood and paper industries. Sustainable forestry practices, including logging, timber processing, and the production of wood-based products, underpin the local economy, supporting a robust presence in the global paper and pulp market. Alongside manufacturing, logistics, and tourism, forestry forms the backbone of Kouvola's economy, capitalizing on its rich natural resources.

In recent years, circular economy business models (CEBMs) have emerged as a promising approach to harness forest by-products, particularly wood residues, to promote sustainable energy production and resource efficiency. These models are essential in minimizing waste, optimizing resource use, and contributing to Finland's ambitious renewable energy goals.

The Keltakangas Waste Station in the Kymenlaakso region exemplifies how circular economy principles can be applied to waste valorization and biogas production, while

Koumet showcases the transformation of forest residues into biochar. The increasing global emphasis on sustainable waste management and renewable energy solutions highlights the importance of analyzing these innovative models, assessing their viability, efficiency, and potential policy implications.

The adoption of circular economy models in the Kouvola region demonstrates significant potential in enhancing resource efficiency and promoting sustainability. Proponents of these models argue that, by converting forest residues into bioenergy and valorizing waste materials, these businesses reduce environmental impact while contributing to Finland's renewable energy targets. Moreover, the integration of biogas production and biochar manufacturing provides economic opportunities through job creation, innovation, and regional development.

However, critics highlight several challenges in scaling these models. The logistical and financial complexities of managing waste valorization and biomass sourcing can hinder the expansion of such initiatives. Furthermore, there is a risk of insufficient infrastructure to support large-scale operations, and regulatory challenges may impede progress, particularly in adhering to evolving environmental standards. The financial viability of these projects also depends on market demand for bioenergy and biochar products, which may fluctuate.

Despite these challenges, the opportunities for growth and innovation in the bioeconomy sector are substantial. Circular economy models offer businesses the chance to diversify revenue streams, optimize resource utilization, and contribute to the global sustainability agenda. Additionally, the potential for scaling up bioenergy production and expanding waste processing facilities aligns with Finland's commitment to a green economy and carbon neutrality. By addressing these challenges through strategic partnerships and technological advancements, the region can further enhance the effectiveness of these models. Thus, the primary objective of this study is to evaluate the operational and economic feasibility of circular economy business models based on forest by-products in the Kouvola region, focusing on the two case studies: the Keltakangas Waste Station and Koumet. This research aims to uncover the challenges and opportunities associated with enhancing circular economy frameworks within the bioeconomy sector. By providing a comprehensive analysis of these initiatives, this study seeks to inform policymakers about potential improvements in regional bioeconomy strategies and sustainable forestry policies.

In particular, this study explores the financial, operational, and strategic implications of different scaling strategies in circular economy business models (CEBMs). It examines how conservative, moderate, and aggressive scaling approaches impact financial risk, sustainability, and resource allocation. Additionally, this study investigates the key factors influencing the scalability and long-term viability of Keltakangas and Koumet, considering financial efficiency, cost management, and market expansion. The role of regulatory frameworks and external market conditions in shaping business growth and financial stability is also analyzed. Lastly, this research explores strategies for enhancing supply chain circularity while pursuing business expansion, ensuring both economic and environmental sustainability. Beyond empirical investigation, this study introduces the concept of "Scalability Path Dependency" (SPD) as a key theoretical lens. SPD describes how the scalability of circular economy business models is shaped not just by financial and operational factors, but also by structural, ecological, and institutional dynamics. By foregrounding this concept, this study bridges the empirical analysis with broader theoretical debates on circular transitions and sustainable growth. It contributes to CEBM theory by offering a multidimensional framework that situates scalability within sector-specific ecological and infrastructural constraints.

The findings hold significant policy implications, particularly for refining bioeconomy regulations and incentivizing sustainable business practices. Policymakers can use these insights to promote investment in bioenergy projects, ensuring alignment with long-term sustainability objectives. From a managerial perspective, this study emphasizes the importance of resource efficiency, cost-effective biomass processing, and the role of automation in waste management. The lessons derived from these case studies can assist businesses in the forestry and bioenergy sectors in optimizing their operations and exploring technological advancements. Unlike general theoretical discussions, this study provides practical insights drawn from real-world implementation, offering value to policymakers, professionals, and researchers. It bridges the gap between theoretical frameworks and practical applications in sustainable resource management, making it a crucial addition to the discourse on circular economy and sustainable development.

2. Literature Review

2.1. Circular Bioeconomy and Sustainable Forestry

A number of studies focus on the role of forestry in the circular bioeconomy, underscoring the importance of sustainable forest management, innovation in bio-based products, and the economic potential of transitioning towards bioeconomy models. These studies highlight how forest-based industries can adopt circular principles through initiatives such as biorefineries, sustainable logging practices, and the development of novel materials like biochar and wood-based bioplastics [1–10]. Forest-based bioeconomy models are often presented as crucial for reducing carbon emissions, creating green jobs, and diversifying the forest industry's output. However, critics raise several concerns. For instance, circular forestry models encounter economic and operational barriers, including market uncertainties, regulatory challenges, and the inherent tension between resource efficiency and biodiversity conservation [2]. Additionally, large-scale bioeconomy initiatives are sometimes criticized for prioritizing economic gains over ecological sustainability, potentially compromising the long-term viability of forest ecosystems [11]. Furthermore, logistical constraints and financial risks often prevent forestry residues from being fully utilized, leading to underinvestment and inefficiency [9].

2.2. Circular Bioeconomy and Bioenergy Production

The utilization of biomass from forest residues as a source of bioenergy is a key theme in many studies, with arguments focusing on its potential to reduce reliance on fossil fuels while promoting regional energy independence. For example, case studies from India and Costa Rica illustrate the environmental and financial feasibility of bioenergy projects, highlighting biochar and wood pellets as critical products for sustainable energy transitions [12–17]. Biochar, in particular, is emphasized for its dual role in energy generation and its soil-enhancing properties, further contributing to sustainability. Despite these positive aspects, challenges in bioenergy production persist. These include high initial capital investment, policy uncertainty, and the variability of biomass supply [15]. Additionally, critics argue that large-scale bioenergy production could lead to land-use conflicts, soil degradation, and the potential for carbon debt if not carefully managed [13]. Some researchers also contend that the economic viability of bioenergy projects is often limited without robust government incentives, which may not always be forthcoming [16].

2.3. Circular Business Models and Innovation

Circular business models (CBMs) are recognized as integral to achieving sustainability goals, with many studies highlighting the role of innovation, digital integration, and collaborative consumption in scaling circular practices. These models, such as product-as-a-service and closed-loop manufacturing, are seen as key to driving sustainable transitions [18–22]. Bocken et al. [18] offer insights from real-world experimentation with circular business models, while Botsman and Rogers [19] explore the growing trend of collaborative consumption as a means to reduce waste and optimize resource use [19,20]. However, these models are not without their challenges. Critics argue that many circular business models remain niche, failing to achieve mainstream adoption due to consumer resistance, financial risks, and operational inefficiencies [20]. Tukker [20] notes that product–service systems require substantial infrastructure investments and behavioral changes, which can hinder their scalability and widespread implementation [22]. Business model innovation plays a crucial role in driving circular transitions, with studies emphasizing experimentation, stakeholder engagement, and digital integration [23–25]. However, many studies overlook the potential of cross-sector synergies and hybrid models, which could enhance scalability [26]. Additionally, research on data-driven decision making in circular businesses often fails to address implementation barriers such as cost constraints and infrastructure limitations [27]. The long-term financial feasibility and viability of circular business models are also underexplored [28].

2.4. Financial and Policy Challenges in Circular Economy Implementation

Financial feasibility and policy support are crucial for scaling circular economy models. Several studies highlight the role of impact investing, blended finance, and policy incentives in overcoming financial barriers to circular economy adoption [29]. The European Union's Circular Economy Action Plan is frequently cited as a key driver of regulatory advancements, with studies emphasizing its role in shaping national and regional policies [30]. Furthermore, Munonye [29] discusses how integrating circular economy principles into business strategies can enhance corporate sustainability, providing a roadmap for companies seeking to align with circular goals [31]. Financing remains a critical challenge for scaling circular economy business models (CEBMs), with research emphasizing impact investing, blended finance models, and public–private partnerships as potential solutions [32]. However, there is a lack of empirical studies assessing the effectiveness of these financial models [33]. Much of the financial sustainability research focuses on sharing economy models, neglecting capital-intensive businesses such as waste valorization and sustainable manufacturing. Additionally, financial risk management remains an underexplored area, particularly in terms of return on investment (ROI) and long-term viability. On the other hand, challenges remain, including policy fragmentation, the lack of standardized metrics, and short-term financial risks that hinder widespread adoption [34]. Scholars argue that EU countries exhibit varying levels of circular economy progress, complicating the implementation of cohesive policies [34]. Additionally, there are concerns that current financing mechanisms do not adequately address the long-term investment risks associated with circular business models, especially in sectors like forestry and bioenergy [29]. Scaling circular economy business models (CEBMs) is influenced by factors like organizational learning, partnerships, and dynamic capabilities [35,36]. However, sector-specific studies indicate significant scalability challenges, particularly in industries such as fashion retail, where rigid supply chains and issues with consumer adoption impede progress [37,38]. Circular start-ups, while innovative, often struggle with profitability and market penetration [39]. Despite these insights, research remains fragmented across industries, making it difficult to develop universally applicable scaling strategies.

2.5. Corporate Governance, Regulation, and Their Impact on Scalability

Corporate governance and regulatory frameworks significantly influence the scalability of circular economy business models (CEBMs). Research points to the importance of board oversight, sustainability reporting, and compliance in shaping business outcomes [40]. Large firms face jurisdictional complexities, while SMEs often struggle with financing and securing institutional support [41]. Although technological advancements like IoT and decision-support systems could improve efficiency, empirical validation remains scarce [42]. Regulatory inconsistencies further exacerbate the barriers that businesses face, yet little research has explored how businesses navigate these challenges.

2.6. Bridging the Gap

The existing literature on the circular bioeconomy highlights valuable insights, but significant gaps remain that this study seeks to address. One key gap is the financial sustainability and scaling strategies of circular forestry models, particularly for biochar and biogas. While these models are discussed theoretically, their long-term economic performance has not been fully explored. This study aims to examine the financial viability of these models over extended periods, offering insights into their scalability and sustainability. Another gap is the lack of concrete examples regarding the regulatory and infrastructure barriers businesses face in circular economy landscapes. While policy challenges are often discussed, practical examples of how businesses navigate these obstacles are limited. This research focuses on real-world case studies in Finland to provide actionable insights into overcoming regulatory hurdles. Additionally, there is a lack of comparative analysis between different scaling strategies for circular economy business models. Most studies focus on either capital-intensive or resource-efficient models without directly comparing the two. This study contrasts two distinct strategies—one relying on external financing and the other emphasizing cost-efficiency and diversification—providing a deeper understanding of how these models can be scaled effectively. By addressing these gaps, this study contributes empirical evidence and practical recommendations, particularly for forestry-based circular business models. It provides insights into the financial performance, scalability, regulatory challenges, and sustainable resource utilization within this sector.

2.7. Theoretical Positioning of Scalability Path Dependency (SPD)

The concept of Scalability Path Dependency (SPD) is grounded in classical path dependency theory [42,43] and socio-technical transition studies [44]. This literature argues that initial conditions and institutional arrangements heavily influence long-term trajectories, often creating self-reinforcing mechanisms that reduce flexibility. In circular economy contexts, SPD highlights how early infrastructural choices, policy alignments, or resource dependencies can constrain future adaptation and innovation. This framework extends traditional scaling theory by embedding it within ecological and systemic constraints.

3. Data and Methods

3.1. Data Sources

This study utilizes both primary and secondary data sources to analyze circular economy business models (CEBMs) in Kouvola, Finland. The primary data includes interviews with managers, operational reports from Keltakangas Waste Station and Koumet, and field observations. Secondary data sources comprise financial records from ORBIS database for 2020–2023, industry reports, regulatory frameworks, and the academic literature on circular economy practices in waste management and forestry.

3.2. Case Study Selection

This study utilizes a comparative case study approach, focusing on two distinct circular economy business models (CEBMs). The first case, Keltakangas Waste Station (NACE 3821—Waste Management and Biogas Production), is a municipal waste processing facility that converts wood waste into biogas, providing renewable energy to over 2000 households and businesses. The second case, Koumet (NACE 220—Forestry and Biochar Production), is a forestry company that employs sustainable harvesting methods and produces biochar to enhance soil fertility and support carbon sequestration. These cases were selected due to their critical roles in regional circular economy initiatives and their contrasting business models—one being infrastructure-intensive and the other resource-efficient. The selected cases—Keltakangas and Koumet—represent two archetypal circular economy business models (CEBMs): the former exemplifies a capital-intensive, infrastructure-heavy approach focused on waste valorization and energy generation; the latter reflects a resource-efficient model emphasizing ecological sustainability and niche market specialization. Their contrasting structures and scaling logics make them ideal for comparative analysis, allowing this study to derive broader insights into scaling strategies across diverse CEBM types.

3.3. Methodology

This study employs a comparative case study approach to analyze the financial, operational, and strategic implications of different scaling strategies in circular economy business models (CEBMs). To examine how different scaling strategies (conservative, moderate, aggressive) influence financial risk, sustainability, and resource allocation, financial and operational data from Keltakangas and Koumet will be collected and analyzed. This will test the hypothesis:

H1. *Moderate scaling is the most financially sustainable approach, balancing growth with risk management*.

This study will also explore how resource allocation varies across scaling strategies, testing the hypothesis

H2. *Aggressive growth requires greater capital and workforce expansion, whereas conservative scaling prioritizes efficiency and existing resources*.

Furthermore, to understand how regulatory frameworks and market conditions shape the growth and financial stability of circular economy businesses, this study will examine industry reports, policy documents, and external market influences. This will validate the hypothesis

H3. *Regulatory policies significantly impact business strategies and financial outcomes*.

Finally, to explore how circular economy businesses can optimize supply chain circularity while scaling operations, this study will analyze supply chain processes and sustainability strategies. This will test the hypothesis

H4. *Enhancing circularity through waste by-product reintegration improves sustainability while maintaining economic viability*.

A mixed-method approach was employed, integrating both qualitative and quantitative analyses. The financial analysis examined revenue trends from 2020 to 2023, assessed profitability metrics such as Net Profit Margins and capital efficiency, and projected five-year growth scenarios. The operational and strategic evaluation reviewed scalability strategies, including infrastructure investments, process optimizations, and market expansion potential, while identifying key challenges and opportunities. Additionally, the policy and regulatory assessment analyzed Finland's waste management and forestry regulations, evaluating government incentives and policy recommendations to support circular economy adoption. Lastly, the sustainability and circularity assessment examined waste valorization, bioenergy utilization, and carbon sequestration potential, highlighting sustainability gaps and areas for improvement. This study applied four analytical dimensions—economic viability, environmental impact, scalability potential, and strategic alignment—to assess each business model's profitability, resource efficiency, expansion feasibility, and policy compatibility.

4. Results

4.1. Case Studies

4.1.1. Keltakangas Waste Station, Kymenlaakso

The Keltakangas Waste Station operates under a comprehensive business model focused on the valorization of wood waste sourced from households and businesses in the Kymenlaakso region. The Keltakangas Waste Station is owned by a consortium of nine municipalities, which initially invested EUR 7 million, followed by an additional EUR 3 million into upgrading the heating plant. The Ministry of Economy contributed about EUR 600,000, with the remaining funds sourced from private capital. The company responsible for the management is the Kymenlaakson Jäte. Figure 1 illustrates two key elements of the biogas production process. The top image shows the wood residue container, where collected lignocellulosic waste materials are stored for processing. In the second image, the interior of the plant is depicted, highlighting one of the boilers used in the facility. These boilers play a crucial role in utilizing the produced biogas to generate heat, contributing to the plant's energy efficiency and sustainability.

Figure 1. The wood residues container (**top**) and the interior of the plant with one of the boilers (**bottom**).

This facility plays a critical role in waste collection and transportation, providing these services free of charge for most wood waste, except for certain types that require specialized treatment. Once collected, the wood waste—primarily consisting of lignocellulosic materials—is transported to a centralized facility for biogas production through anaerobic digestion. Because lignocellulosic biomass is structurally complex and resistant to microbial breakdown, it must first undergo pre-treatment. This begins with mechanical processing such as shredding or grinding to reduce particle size and increase surface area. Other organic wastes, including paper pulp, may also be incorporated into the feedstock to optimize the digestion process. Once adequately pre-treated, the material is fed into an anaerobic digester where it undergoes a four-stage biological conversion process. In hydrolysis, complex carbohydrates are broken into simple sugars; acidogenesis then transforms these into volatile fatty acids, alcohols, and gases; acetogenesis further converts these intermediates into acetic acid, carbon dioxide, and hydrogen; finally, methanogenesis produces biogas—primarily methane and carbon dioxide—via methanogenic archaea. The biogas is collected and may be used directly for heat production.

The facility is equipped with two boilers and a pipeline system that helps distribute the generated biogas. The operation is highly automated, with a single employee remotely overseeing the process using advanced control systems. Figure 2 shows the software system used to control and monitor all operations within the biogas production facility. This software enables the real-time tracking of processes and the adjustment of operational parameters, and it ensures the smooth coordination of activities such as feedstock handling, anaerobic digestion stages, and energy output management. It plays a vital role in optimizing efficiency and maintaining consistent production quality.

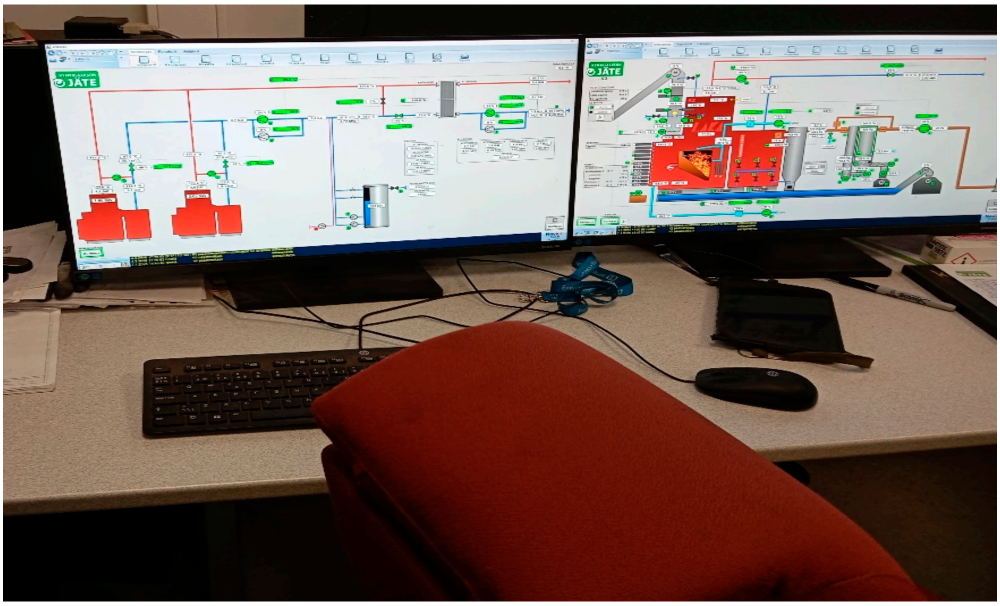

Figure 2. The software that allows the control of all operations.

Around 2000 households in the region have invested in the necessary equipment and piping installations to use biogas for heating. Businesses are required to independently arrange for waste transport, but smaller waste quantities can be disposed of at local stations. Larger truckloads are directed to Keltakangas, which is operated by Ekokaari Oy. Kymenlaakson Jäte, the primary waste management provider in the region, is responsible for the collection of residual and biowaste in several municipalities, including Iitti, Kotka, Kouvola, and Mäntyharju. Residents of other municipalities are free to choose their waste transport providers. The region has several waste stations across various municipalities, including Kouvola, Iitti, Kotka (Jumalniemi), Lapinjärvi, Mäntyharju, Hamina, Pertunmaa, Miehikkälä, and Virolahti. These stations accept sorted waste unsuitable for household bins, and payment can be made via bank card or MobilePay. Additionally, these stations offer several services, such as trailer rentals, eco-points, and circulating collections for hazardous waste, electrical items, and scrap metal. There are also paid pickup services for garden waste, bulky items, Christmas trees, and farm plastics. Figure 3 presents the fluxogram of the circular economy business model (CEBM) implemented by Kymenlaakson Jäte. This diagram illustrates the flow of materials and processes within the system, highlighting how waste streams are collected, processed, and transformed into valuable outputs such as biogas.

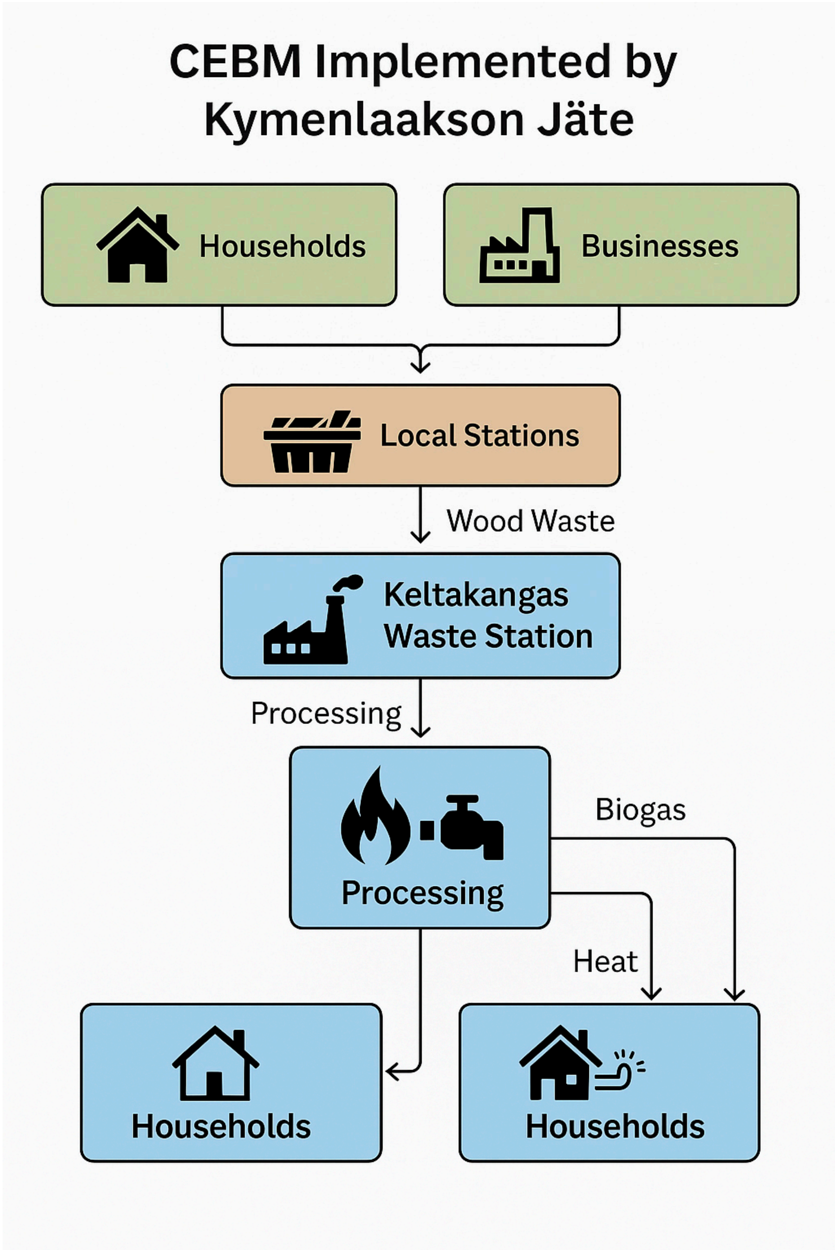

Figure 3. Fluxogram of the CEBM implemented by Kymenlaakson Jäte.

As of May 2024, residents of single-family homes in Kotka, Hamina, and Kouvola were required to sort their biowaste or compost it. To comply with this new regulation, residents have several options: they can register for biowaste collection, share a biowaste container with neighbors, or self-compost and notify the Kymi Waste Board. Those already composting their food waste must submit a composting notification to Kymenlaakson Jäte if it was not performed by 20 May 2022. Biowaste collection options include the provision of a container, which is emptied by a garbage truck. Residents can choose from ventilated biowaste containers (140 L), emptied every 4 weeks, or regular biowaste containers (140–240 L), which must be manually movable and emptied every 2–4 weeks, depending on the season. Shared containers are also available for neighbors to reduce costs. Alternatively, residents can purchase a compliant food waste composter for self-composting, with the composted soil usable for yard gardening. In this case, there are no fees for biowaste collection, and residual waste collection intervals are extended.

Biowaste Sorting Expansion (2026): By 1 May 2026, detached and semi-detached houses in smaller settlements, including Elimäki, Myllykoski, and Pyhtää, will also be required to sort biowaste through either collection or composting. Sparsely populated areas are exempt from this regulation, but voluntary composting is allowed with proper notification. The Finnish Environment Institute discussed the national waste plan, which aims to increase municipal waste recycling rates to 57% by 2027 and improve biowaste recycling to 65%. The Finnish Renewable Energy Association emphasized the role of waste management in the circular economy and highlighted the Waste Act (revised in 2021), which governs municipal waste transport. An update of the regional waste policy program for 2025–2030 aims to promote sustainable resource use, prevent environmental damage, and enhance municipal cooperation.

Shared Biowaste Container Trial: Kymenlaakson Jäte conducted a trial in Kotka and Kouvola, where twelve neighboring properties shared biowaste containers. The results revealed that half of the participating households saved over EUR 170 per year due to extended intervals between emptying residual waste containers when biowaste was separated. However, the other half saw a slight increase in costs, ranging from EUR 13 to EUR 30 annually, due to the ineffective extension of emptying intervals. Despite this, the trial demonstrated environmental benefits, such as increased efficiency in waste collection and improved biogas production. These trials contribute to shaping future strategies for biowaste management in the region, ensuring compliance with upcoming regulations and promoting sustainable practices. Overall, the ongoing efforts to improve biowaste sorting and collection in the Kymenlaakso region reflect a commitment to cost-effective and environmentally friendly solutions. The Keltakangas Waste Station, along with other waste management initiatives, plays a vital role in shaping the region's waste management policies and practices.

4.1.2. Koumet

Located in Kouvola, Finland, the company has emerged as a leader in the forestry sector over the past decade by combining innovative forestry management with sustainable biochar production. The company's evolution from a small logging business founded in 2010 to a comprehensive provider of forest services demonstrates its ability to adapt and grow while integrating eco-friendly practices and cutting-edge technology. A standout feature of Koumet's operations is the development of a specialized machine designed for harvesting willows, a key material used in the production of biochar. This biochar, when blended with organic materials like sewage or chicken manure, creates a high-value product suitable for gardening and landscaping, thereby adding an additional revenue stream while promoting sustainability. Koumet's business model is based on providing high-quality forest services to both large forestry companies and private landowners. Initially, the company focused on timber harvesting but soon expanded its offerings to include forest management and specialized infrastructure services. Key services include timber harvesting for energy production, forest management, and high-risk tree felling operations near infrastructure such as power lines, railways, and roads. This broad range of services has made Koumet a go-to provider for a variety of clients, including those in need of specialized forest management solutions. One of the company's major innovations is its biochar production, a process in which biomass, particularly harvested willows, is converted into biochar through pyrolysis. Biochar is a stable form of carbon that is used to enhance soil quality by improving water retention, nutrient availability, and promoting plant growth. By developing a unique machine designed specifically for the efficient harvesting of willows, Koumet has been able to tap into the growing market for sustainable gardening products. The company's biochar can be mixed with organic waste such as sewage sludge or chicken manure to produce an eco-friendly soil amendment that is highly sought after in landscaping and horticulture. This initiative not only benefits the environment but also creates a new revenue stream for the company. In addition to biochar production, Koumet's commitment to sustainable forestry practices is evident through its forest management services. The company employs continuous-cover forest management, a technique that avoids clear cutting and ensures a mixed-age forest system. This method promotes biodiversity, optimizes carbon sequestration, and supports the long-term health of the forest ecosystem. Furthermore, the company's involvement in the energy wood trade contributes to the growing demand for renewable energy. By sourcing wood from young forests and crown mass from regeneration fellings, Koumet supports the energy sector while promoting sustainable forest use. Koumet's success also hinges on its strategic partnerships with local entrepreneurs and subcontractors. The company collaborates with a network of around 30 local contractors, including Koneurakointi Isto Paasonen Ky, a key partner since 2012. These partnerships allow Koumet to maintain flexibility in its operations and offer a wide range of services, including nature conservation, environmental services, and controlled burns for forest land cultivation. This ability to collaborate with local businesses enables Koumet to adapt to the diverse needs of its clients, ranging from large forestry operators to private landowners. Figure 4 illustrates the fluxogram of the CEBM implemented by Koumet. This diagram details the flow of raw materials, primarily wood residues and biomass, through various processes including harvesting, biochar production via pyrolysis, and sustainable forestry practices.

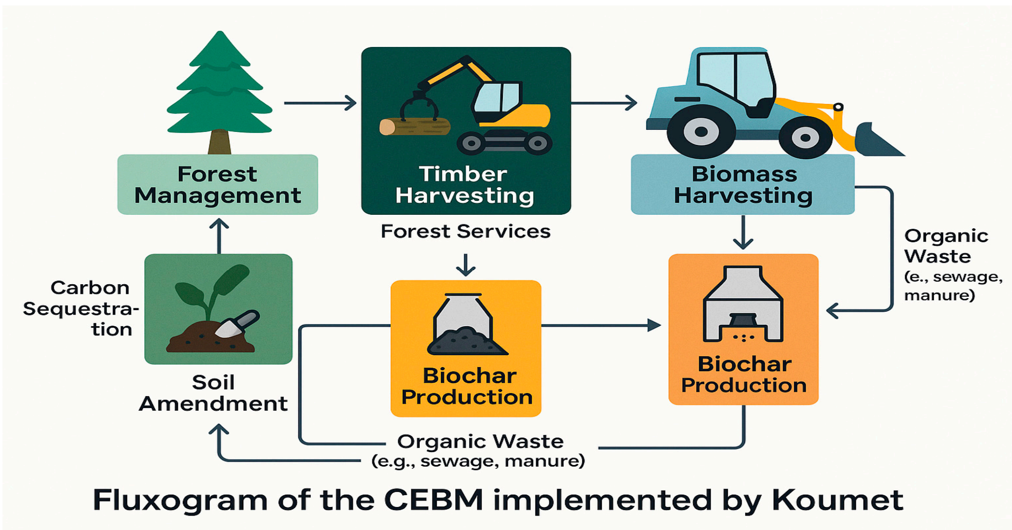

Figure 4. Fluxogram of the CEBM implemented by Koumet.

The company's sustainable approach to forestry and biochar production is designed to minimize environmental impact while maximizing the ecological and economic value of the forest. This is reflected in its focus on biodiversity management, soil improvement through biochar, and carbon sequestration. As the company continues to grow, Koumet plans to expand its biochar production and explore new markets for its forest-based products. However, scaling up production will present challenges, particularly regarding the sourcing of biomass to meet the increasing demand for biochar while maintaining the sustainability and quality of its operations. Looking ahead, Koumet remains committed to developing new technologies and processes to enhance the sustainability and efficiency of its operations. The company's combination of traditional forestry services with innovative, environmentally friendly solutions has carved out a unique niche in the market. As it continues to expand, Koumet aims to remain at the forefront of the forestry industry by integrating sustainability into every aspect of its business model, ensuring that both the environment and the economy benefit from its operations. In conclusion, Koumet's success is a testament to its innovative approach to forestry management and biochar production. By combining traditional expertise with modern sustainability practices, the company has positioned itself as a leader in the sector. Its ongoing commitment to eco-friendly solutions and its ability to adapt to changing market demands ensure that Koumet will remain a key player in the sustainable forestry industry for years to come.

4.2. Environmental and Social Impacts

Keltakangas Waste Station operates a circular business model by converting forestry residues, such as sawdust and branches, into biogas through anaerobic digestion or gasification. This process not only generates renewable energy but also reduces wood waste, aligning with sustainability goals. The residual digestate from biogas production is reintegrated into agriculture as biofertilizer, closing the nutrient cycle. The company's revenue is primarily derived from selling biogas to energy providers, supported by collaborations with families, firms, and municipalities. By replacing fossil fuels and minimizing CO_2 emissions, Keltakangas contributes significantly to environmental sustainability. Koumet follows a resource-efficient model by using pyrolysis to transform wood waste into biochar, a soil-enhancing material that improves water retention and sequesters carbon. This product serves multiple markets, including agriculture, landscaping, and soil restoration, creating a diversified revenue stream. The circular supply chain ensures that biochar supports sustainable forestry by enhancing soil productivity, reducing chemical fertilizer dependence, and facilitating long-term carbon sequestration. Table 1 presents a comparison of key sustainability parameters between Keltakangas Waste Station and Koumet.

Table 1. Comparison of sustainability parameters: Keltakangas vs. Koumet.

Case Study Parameters	Keltakangas Waste Station	Koumet
Waste/Resource Utilization	Valorization of wood waste, biogas for heating, and recycling of waste materials.	Use of biomass (willows, organic waste) to produce biochar for gardening, energy, and carbon sequestration.
Environmental Impact	Reduced waste in landfills, biogas as a renewable energy source, and sustainable waste management practices.	Enhanced soil quality, improved biodiversity, carbon sequestration, and minimized environmental footprint of forestry.
Regulatory Framework	Waste management regulations, mandatory biowaste sorting (2024–2026).	Forestry regulations, sustainable land management policies, biochar product standards.
Social/Community Impact	Improved waste management infrastructure, biogas heating for households, community involvement in waste sorting.	Support for local landowners, job creation in sustainable forestry, community awareness of biochar benefits.
Sustainability Goals	Promote recycling, circular economy principles, and reduce carbon footprint.	Support sustainable forestry practices, promote renewable energy, and reduce environmental degradation.

4.3. Economic Viability

Table 2 summarizes key financial and operational metrics for Keltakangas Waste Station and Koumet over a four-year period, highlighting trends in scale, profitability, liquidity, efficiency, and capital intensity.

Table 2. Summary table of financial analysis.

Category	Indicator	Company	2020	2021	2022	2023	Trend (2020–2023)
Scale and Size	Turnover (EUR K)	Keltakangas	24.22	24.53	23.25	24.92	→ Stable
		Koumet	5.91	7.02	6.31	7.96	↑ Growing
	Total Assets (EUR K)	Keltakangas	41.65	39.45	37.25	41.02	→ Fluctuating
		Koumet	1.94	2.12	2.02	2.33	↑ Growing
Profitability Ratios	Gross Profit Margin (%)	Keltakangas	8.8	12.0	6.7	6.3	↓ Decreasing
		Koumet	4.5	3.1	3.1	3.3	→ Stable
	Net Profit Margin (%)	Keltakangas	6.8	9.5	5.3	4.9	↓ Decreasing
		Koumet	3.3	2.5	2.3	2.7	→ Stable
Return on Investment	ROE (%)	Keltakangas	9.6	16.0	6.7	5.3	↓ Declining
		Koumet	17.2	13.6	12.3	15.6	→ Fluctuating
Liquidity and Solvency	Current Ratio	Keltakangas	3.0	3.0	3.0	2.0	↓ Declining
		Koumet	2.0	2.0	2.0	2.0	→ Stable
	Solvency Ratio (%)	Keltakangas	41	46	49	56	↑ Improving
		Koumet	59	61	59	58	→ Stable
Operational Efficiency	Productivity (Rev/Emp) (EUR K)	Keltakangas	433	438	342	356	→ Stable
		Koumet	996	1004	1052	996	→ Stable
Capital Intensity	Tangible Assets (EUR K)	Keltakangas	25,161	24,433	21,285	24,724	→ Stable
		Koumet	410	415	343	334	→ Stable

The financial analysis of the two companies operating under NACE 3821 (Waste Management) and NACE 0220 (Forestry and Biochar) reveals significant differences in scale, profitability, and business models. The waste management company (Keltakangas) is considerably larger in terms of turnover, total assets, and workforce, with a revenue of EUR 24,920 K in 2023 compared to EUR 7967 K for the forestry company (Koumet). With 70 employees in 2023, it employs nearly nine times as many workers as the forestry company, which has only 8. This suggests a capital-intensive business model in waste management, requiring substantial infrastructure and operational capacity. Conversely, the forestry and biochar firm operates on a much smaller scale, reflecting a leaner and more specialized approach.

Profitability indicators further highlight the structural differences between these firms. The waste management company maintains higher Gross and Net Profit Margins, achieving a Gross Profit Margin of 6.33% and a Net Profit Margin of 4.87% in 2023. In contrast, the forestry company operates with significantly lower margins, reporting a Gross Profit Margin of 3.28% and a Net Profit Margin of 2.66%. Despite its lower absolute profitability, the forestry firm demonstrates superior capital efficiency, with a Return On Equity (ROE) of 15.6% compared to 5.3% for the waste management firm. This suggests that, while the waste sector benefits from economies of scale, the forestry company operates with a high degree of financial efficiency, maximizing returns on limited shareholder funds.

Both firms exhibit strong financial stability, with comparable solvency ratios of 56% and 58%, indicating balanced debt-to-equity structures. The current ratio, a measure of liquidity, stands at 2.0 for both, suggesting that each company maintains sufficient short-term assets to meet its liabilities. However, their productivity and capital efficiency diverge significantly. The waste management firm has a larger tangible asset base of EUR 24,724 K in 2023, yet its productivity per employee is relatively low at 356. In contrast, the forestry company, with a much smaller asset base of EUR 334 K, achieves a productivity level nearly three times higher at 996 per employee, indicating a more labor-efficient model.

From a circular economy business model (CEBM) perspective, the waste management firm relies on a capital-intensive infrastructure designed for waste processing, recycling, and potentially waste-to-energy initiatives. Its profitability remains stable due to the consistent demand for waste management services, but high infrastructure costs and regulatory constraints pose long-term challenges. Meanwhile, the forestry and biochar company follows a resource-efficiency-driven model, leveraging biomass transformation into biochar and sustainable forestry management. While its revenue base is smaller, its efficient use of capital and labor makes it a resilient business in terms of financial sustainability. However, scalability remains a challenge, as profitability margins are relatively low.

Overall, the waste management company operates on a large-scale, infrastructure-dependent model that benefits from stable demand but requires continuous investment in assets. The forestry and biochar company, on the other hand, follows a leaner, high-efficiency approach, demonstrating strong capital utilization despite lower absolute profits. These differences highlight distinct pathways within the circular economy: one driven by heavy infrastructure and regulatory frameworks and the other by resource optimization and niche market specialization.

In addition to ROE and profit margins, two supplementary indicators—EBITDA and Asset Turnover ratio—were analyzed to enhance model robustness. EBITDA provides a clearer picture of operational cash flow by excluding depreciation and financing effects, while the Asset Turnover ratio assesses how efficiently each company uses its asset base to generate revenue. These metrics are presented and discussed in Appendix A.

4.4. Scalability Potential

4.4.1. Opportunities to Scale-Up

Data for this analysis (see Table 2) were sourced from the financial reports of the Keltakangas Waste Station (NACE 3821) and Koumet in Kouvola (NACE 0220), covering the period 2020 to 2023. The primary goal was to identify the most significant financial drivers impacting profitability, measured by Return on Equity (ROE). Financial metrics were categorized into Scale and Size (Turnover, Total Assets), Profitability Ratios (Gross Profit Margin, Net Profit Margin), Return on Investment (ROE), Liquidity and Solvency (Current Ratio, Solvency Ratio), Operational Efficiency (Productivity), and Capital Intensity (Tangible Assets). Percentage values were converted to decimal form for uniform scaling, and all data were standardized to prevent bias from varying magnitudes. The Lasso (Least Absolute Shrinkage and Selection Operator) method was chosen due to its ability to both regularize and select features, enhancing model interpretability by driving some coefficients to zero. This was particularly useful given the multicollinearity often present in financial datasets. The Lasso loss function is defined as

$$L = MSE + \alpha \sum_{J=1}^{P} |\theta j| \quad (1)$$

where *MSE* is the mean squared error, α is the regularization parameter controlling the penalty strength, and θj are the coefficients of the predictor variables. The model was trained using a matrix formulation of independent variables (X) and the dependent variable (Y) as ROE. Cross-validation (k-fold) was applied to identify the optimal parameter, balancing bias and variance.

NACE 3821—Keltakangas Waste Station

The Lasso regression analysis identified Net Profit Margin (%) as the only non-zero coefficient (~0.033), suggesting that it is the primary financial driver of ROE. All other variables, including liquidity, assets, and productivity, were effectively eliminated by the model. Table 3 presents the Lasso regression coefficients for Keltakangas Waste Station (NACE 3821), identifying key financial and operational variables that influence the company's Return on Equity (ROE).

Table 3. Lasso regression coefficients for Keltakangas Waste Station (NACE 3821).

Indicator	Coefficient
Net Profit Margin (%)	0.0328
Turnover (EUR K)	0.0000
Total Assets (EUR K)	0.0000
Gross Profit Margin (%)	0.0000
Current Ratio	0.0000
Solvency Ratio (%)	0.0000
Productivity (Rev/Emp)	0.0000
Tangible Assets (€K)	0.0000

These findings emphasize the critical role of maintaining efficient profitability, with Net Profit Margin being the key lever to enhance ROE. This insight supports a strategy focused on margin optimization, cost efficiency, and targeted reinvestments. The results also suggest a highly scalable circular economy business model (CEBM) due to minimal dependency on capital-intensive inputs. The Keltakangas Waste Station shows strong scalability potential driven by operational improvements and sustainability initiatives. Optimizing waste-to-biogas conversion, enhancing logistics, and leveraging government incentives (e.g., carbon credits, recycling targets) are essential for growth. Circular strategies like using digestate as fertilizer or supplying biogas to local industries further improve both circularity and financial performance.

NACE 0220—Koumet (Silviculture)

The Lasso regression analysis revealed no strong financial predictors of ROE. All coefficients were close to zero, indicating weak explanatory power. Table 4 shows the Lasso regression coefficients for Koumet.

These results suggest that profitability in silviculture is not strongly linked to traditional financial indicators, possibly due to sector-specific features such as long biological cycles, climatic variability, and reliance on subsidies. From a circular economy perspective, although silviculture aligns with sustainability goals, the scalability of the CEBM is limited by operational inflexibility and weak financial predictability. Growth strategies should prioritize improving operational efficiency (e.g., biomass conversion), reinvesting profits, and diversifying applications (e.g., soil enhancement, carbon sequestration, water filtration). Koumet has potential in biochar production, sustainable forestry, and energy wood trade. Innovations in willow harvesting and pyrolysis technology support increased capacity. However, expansion will require partnerships, reliable biomass supply, and strategic market entry at national and international levels.

Table 4. Lasso regression coefficients for Keltakangas Waste Station (NACE 0220).

Indicator	Coefficient
Net Profit Margin (%)	0.0075
Gross Profit Margin (%)	0.0039
Productivity (Rev/Emp)	−0.0082
Solvency Ratio (%)	−0.0043
Tangible Assets (EUR K)	0.0000
Total Assets (EUR K)	0.0000
Turnover (EUR K)	0.0000
Current Ratio	0.0000

The lack of significant predictors in the Lasso regression for Koumet may be attributed to several factors. First, the forestry sector is inherently characterized by high variability in profitability due to environmental dependencies and seasonal fluctuations. Second, the biological production cycle in forestry is long and nonlinear, often spanning several years, which complicates year-on-year financial predictability. Third, the small sample size—only four years of financial data—reduces the statistical power of the model and limits its ability to identify robust predictors. These sector-specific and methodological limitations likely contributed to the model's weak explanatory power.

4.4.2. Comparative Analysis of Keltakangas and Koumet

This subsection provides a comparative analysis of two firms: Keltakangas Waste Station (NACE 3821) and Koumet (NACE 0220), focusing on their input sources, technological processes, output types, operational scale, and financial performance based solely on financial data from 2020 to 2023. Table 5 provides a comparative summary of key operational and financial aspects between Keltakangas Waste Station and Koumet.

Table 5. Comparative summary of key operational and financial aspects.

Aspect	Keltakangas Waste Station	Koumet
Input Sources	Processes mainly municipal and industrial waste, requiring extensive infrastructure.	Uses biomass and forestry residues, focusing on sustainable resource use.
Technological Process	Relies on mechanical and biological treatment with large infrastructure investment.	Uses pyrolysis for biochar production with a leaner, smaller-scale setup.
Outputs	Produces treated waste, biogas, and recycled materials, supporting circular economy goals.	Produces biochar for soil improvement and carbon sequestration in niche markets.
Scale and Workforce	Large-scale operation with high turnover and many employees.	Smaller scale but higher labor productivity per employee.
Financial Performance	Moderate profitability with lower ROE due to high fixed costs.	Lower margins but higher ROE reflecting efficient capital use.
Scalability Drivers	Profit margin strongly linked to ROE, supporting financial growth through margin improvement.	No clear financial predictors of growth; scalability depends on operational factors.

Keltakangas primarily processes municipal and industrial waste streams, relying on continuous collection and capital-intensive infrastructure for sorting, treatment, and biogas conversion. Its technological processes involve mechanical and biological methods, notably anaerobic digestion supported by a large asset base, reflecting a complex infrastructure network. This allows Keltakangas to produce treated waste, recycled materials, biogas, and digestate that serve circular economy objectives such as material recovery and renewable energy generation.

In contrast, Koumet operates within sustainable forestry and biochar production, sourcing biomass and forestry residues like willow. Its operations emphasize resource efficiency and biomass transformation via pyrolysis technology, supported by a comparatively modest asset base. Koumet's outputs focus on biochar, which offers environmental benefits such as soil enhancement and carbon sequestration, positioning the firm in a specialized niche of the circular economy.

The operational scale differs significantly: in 2023, Keltakangas reported revenues exceeding EUR 24.9 million with a workforce of 70 employees, indicative of a large-scale, infrastructure-heavy business model. Koumet's turnover stood at approximately EUR 7.97 million with just eight employees, reflecting a leaner organization with higher labor productivity measured by revenue per employee.

Financially, Keltakangas demonstrated moderate profitability with Gross and Net Profit Margins at 6.33% and 4.87%, respectively, alongside an ROE of 5.3%. Koumet, despite lower margins (3.28% gross, 2.66% net), achieved a substantially higher ROE of 15.6%, illustrating more efficient capital use. This suggests that Koumet's smaller-scale operation maximizes returns on limited equity, while Keltakangas relies on economies of scale and substantial fixed investments.

Regarding scalability, Keltakangas exhibits a clear financial driver for growth, with Net Profit Margin closely linked to ROE, supporting strategies that focus on margin optimization and cost control. Conversely, Koumet's financial data lacks strong predictors for ROE, indicating its growth is more contingent on operational advancements, innovation in biomass processing, and market development rather than traditional financial leverage. While internal factors shape the financial and operational profiles of Keltakangas and Koumet, their scalability trajectories are also deeply influenced by external regulatory frameworks. Two policies play a pivotal role in shaping the scaling trajectories of the two companies: the 2026 biowaste sorting mandate and the 2030 landfill diversion targets. For Keltakangas, the biowaste mandate necessitates investment in collection infrastructure and public engagement, increasing short-term operational costs while expanding the customer base in the long term. The landfill diversion targets, meanwhile, create economic incentives for biogas production, reinforcing the scalability of circular waste processing. For Koumet, although less directly affected, these policies enhance the market potential for soil-enhancing products like biochar by increasing organic waste supply and encouraging carbon-sequestering agricultural practices.

4.4.3. Future Scenarios

The biogas company must prioritize financial efficiency and profit margin optimization for growth, with external financing as a potential accelerator, provided it maintains a strong return on investment. The biochar company follows a production-driven model, where cost reduction and market expansion are the primary paths to scalability, allowing for sustainable growth without immediate reliance on external funding.

The scaling scenario assumptions include a low growth rate of 5%, a medium growth rate of 10%, and a high growth rate of 15% for turnover and related metrics. Table 6 outlines three distinct scaling scenarios—Conservative, Moderate, and Aggressive—for the two companies. The comparison illustrates how each firm's strategic approach to scaling influences financial stability, operational demands, and sustainability goals, providing a framework to support decision making under varying growth ambitions and risk tolerances.

Table 6. Scaling scenarios and strategic implications for the two companies.

		Scenarios		
Company	**Parameter**	**1: Conservative Scaling**	**2: Moderate Scaling**	**3: Aggressive Scaling**
Keltakangas	Turnover Increase	Steady growth maintaining current workforce and operational capacity, focusing on process efficiency.	Moderate expansion in services and regional coverage, requiring some increase in workforce and investment in technology.	Rapid expansion into new markets, requiring major investments in infrastructure and workforce growth.
	Cost Implications	Costs increase proportionally to turnover, with limited efficiency gains. High infrastructure costs limit cost reduction potential.	Increased capital investments in technology and workforce training, but improved economies of scale could mitigate cost pressures.	High upfront costs due to new facilities, logistics expansion, and workforce scaling; risk of cost overruns.
	Profitability	Slow but stable improvement in profits due to efficiency optimizations without major structural changes.	Moderate increase in profit margins as economies of scale begin to take effect.	Short-term profit reduction due to high capital investment, but long-term gains if market share is successfully expanded.
	Implications for CEBM	Aligns with long-term financial stability, with a focus on optimizing existing waste management processes. Low-risk approach.	Balances growth with sustainability, leveraging economies of scale while maintaining financial and operational stability.	Aligns with aggressive sustainability goals but introduces financial risks; requires strong strategic execution.
Koumet	Turnover Increase	Incremental revenue growth from process improvements and gradual market penetration.	Expansion into new agricultural and industrial biochar applications, increasing production capacity and market reach.	Large-scale expansion into national and international biochar markets, requiring substantial capital investments.
	Cost Implications	Minimal additional costs, focusing on operational efficiency rather than capital expansion.	Increased investment in production efficiency and supply chain optimization, with manageable cost growth.	High costs due to expansion in production facilities, biomass sourcing, and workforce scaling, potentially requiring external financing.
	Profitability	Steady but limited profit growth, maintaining current efficiency levels and margins.	Improved profitability through market expansion and efficiency gains, with moderate financial risk.	Potential short-term decline in profit margins due to high expansion costs, but long-term profitability could increase if scale economies are realized.
	Implications for CEBM	Strong alignment with sustainable forestry and biochar production, ensuring financial resilience with minimal risk.	Supports gradual integration into new sustainability markets while balancing financial risks.	High-risk, high-reward strategy that could significantly expand circular economy impact but requires careful capital allocation.

CEBMs must evaluate financial risk, sustainability, resource allocation, and strategic focus when selecting a scaling approach. Conservative scaling minimizes risk but limits returns, aggressive scaling offers higher rewards but demands significant investment, and moderate scaling provides a balanced alternative. Sustainability considerations often favor moderate scaling for long-term stability, while aggressive growth can establish industry dominance if well-executed. Resource allocation varies, with aggressive scaling requiring additional funding and workforce expansion, whereas conservative scaling prioritizes efficiency with minimal new investments. Strategic alignment is crucial to ensure that scaling efforts support corporate goals such as market leadership, profitability, or expansion. Ultimately, each approach must balance revenue growth with operational risks to seize market opportunities while maintaining financial stability and sustainability. For Keltakangas, scaling relies on financial efficiency and infrastructure investment. Conservative growth ensures stability, while aggressive expansion introduces higher financial risk but enhances market presence. For Koumet, growth is driven by cost efficiency and market expansion. Moderate scaling balances profitability with sustainability, while aggressive growth requires significant capital but could unlock larger markets.

Based on the financial analysis and Lasso regression results, it is possible to make a quantitative prediction about the relationship between profitability (measured by Return on Equity, or ROE) and scale (captured through turnover growth and operational investment)—but only for Keltakangas Waste Station (NACE 3821). In contrast, Koumet (NACE 0220) does not lend itself to such a prediction, as traditional financial indicators were found to have minimal explanatory power. This suggests that, while Koumet allows for valuable qualitative insights into scaling, it lacks the financial predictability necessary for quantitative modeling.

For Keltakangas, the Lasso regression identified Net Profit Margin as the sole significant predictor of ROE, with a non-zero coefficient of approximately 0.0328. All other financial indicators, such as turnover, total assets, liquidity ratios, and productivity, were effectively eliminated from the model after standardization and regularization. This outcome suggests a strong linear relationship between Net Profit Margin and ROE. Accordingly, we can reasonably estimate ROE as a direct function of Net Profit Margin using the simplified model:

$$\text{ROE} \approx 0.0328 \times \text{Net Profit Margin} \quad (2)$$

By applying this formula to assumed improvements in Net Profit Margin under different scaling scenarios—conservative (5% growth), moderate (10% growth), and aggressive (15% growth)—we can project ROE outcomes as follows: Table 7 presents the projected financial outcomes for the companies under three distinct growth scenarios—conservative, moderate, and aggressive.

Table 7. Projected financial performance under different growth scenarios.

Scenario	Assumed Net Profit Margin (%)	Projected ROE (%)
Conservative (5% growth)	5.0	0.164
Moderate (10% growth)	7.0	0.230
Aggressive (15% growth)	9.0	0.295

The results demonstrate a clear, linear relationship between profit margin and ROE: as the Net Profit Margin increases from 5% to 9%, the ROE correspondingly rises from 0.164 to 0.295. This suggests that Keltakangas's profitability is highly sensitive to changes in operational efficiency rather than top-line growth alone. Economically, this implies that value creation is primarily driven by internal cost control and margin optimization, rather than by scaling revenue through aggressive expansion. The lack of significant influence from turnover or the asset base on ROE further emphasizes this point. Therefore, the most effective strategy for sustainable growth would be to focus on initiatives that directly enhance profit margins—such as investments in production efficiency, logistics optimization, and sustainability measures. These findings indicate a scalable business model, but one that depends fundamentally on maintaining or improving profitability per unit of output, not just increasing volume.

In contrast, a similar quantitative approach cannot be applied to Koumet. The Lasso regression results for this firm showed that all financial predictors had coefficients close to zero. This indicates that ROE is not meaningfully explained by traditional financial indicators in Koumet's case, likely due to the sector's inherent characteristics—such as long biological cycles, environmental variability, and dependency on subsidies. These factors introduce volatility and complexity that undermine the predictive strength of standard financial metrics. Therefore, while Koumet holds promise for growth through innovations in biochar production and sustainable forestry, its scalability must be assessed through operational strategies rather than financial modeling.

Keltakangas demonstrates strong potential for financially efficient scaling, with profitability closely linked to Net Profit Margin improvements. This allows for clear, quantitative projections of ROE under different growth scenarios. In contrast, Koumet does not exhibit the same level of financial predictability; instead, its growth depends on operational innovation, market diversification, and strategic partnerships. Given these dynamics, moderate scaling emerges as the most balanced and sustainable approach for both firms, enabling steady growth while managing financial risk.

4.5. Strategic Alignment

Table 8 compares the strategic focus and stakeholder involvement of two circular economy business models represented by Keltakangas Waste Station and Koumet.

Table 8. Strategic comparison of circular economy business models.

Case Study Parameters	Keltakangas Waste Station	Koumet
Objective	Explore the business model and waste management services, particularly in the valorization of wood waste and biogas production.	Investigate sustainable forestry practices and biochar production, focusing on environmental benefits and economic impact.
Location	Kymenlaakso, Finland.	Kouvola, Finland.
Key Stakeholders	Keltakangas Waste Station, Kymenlaakson Jäte, Municipalities, Households, Businesses	Koumet, Local Contractors, Forestry Companies, Private Landowners.
Business Model/Operations	Waste collection, transportation, and processing; biogas and paper pulp production from wood waste.	Forest services including timber harvesting, biochar production from willows, and energy wood trade.
Technology/Innovation	Automated waste processing systems, biogas production, remote management of operations.	Specialized willow harvesting machine, pyrolysis for biochar production, continuous-cover forest management.
Economic Impact	Job creation in waste management and biogas production, regional economic benefits from sustainable waste processing.	Diversified revenue streams from biochar products, sustainable forestry management, and partnerships with local businesses.
Challenges/Barriers	Logistical and financial challenges in scaling operations, regulatory compliance, and consumer adoption of biowaste sorting.	Biomass sourcing challenges, scaling up biochar production, maintaining sustainability while expanding.
Strategic Partnerships	Consortium of municipalities, private capital investments, cooperation with local waste transporters.	Collaboration with local entrepreneurs and subcontractors, partnerships with forestry companies.
Market/Business Expansion Potential	Expansion of waste management services, increase in biogas customers, upgrade of waste processing facilities.	Scaling up biochar production, expanding market for eco-friendly soil amendments, broadening forestry services.

5. Discussion

5.1. Integration with the Literature and Sector-Specific Insights

The findings corroborate the existing literature on the circular bioeconomy, particularly regarding the role of sustainable forestry practices, bioenergy production, and circular business models in driving environmental sustainability. As highlighted by several studies, the transition to bioeconomy models involves significant challenges, including market uncertainties, regulatory hurdles, and the balancing act between resource efficiency and ecological conservation [2,5]. The findings also align with discussions on the potential of biochar and biogas in reducing carbon emissions and enhancing soil quality [11,13] while emphasizing the importance of policy support and financial feasibility for scaling these models [27].

5.2. Comparative Business Model Analysis and Strategic Implications

The scalability of circular business models is frequently limited by challenges like substantial capital requirements, policy uncertainties, and inefficiencies in supply chains [21,22]. By examining two companies that embody contrasting approaches—one with a capital-intensive waste management model and the other with a resource-efficient forestry and biochar model—this study offers concrete examples of how different circular economy strategies operate in practice. This comparative analysis deepens understanding of the specific scalability barriers and opportunities that each model faces, thereby serving as practical business models that can guide future circular economy ventures in navigating growth within their unique contexts. Table 9 presents a SWOT analysis comparing the scalability potential of the two circular economy business models of Keltakangas Waste Station and Koumet.

Table 9. SWOT analysis of CEBM scalability.

	Keltakangas Waste Station	**Koumet**
Business Model	Capital-Intensive, Waste Processing, and Biogas Resource-Efficient, Biochar, and Forestry	Resource-efficient, biochar, and forestry
Strengths	Economies of Scale Stable Profitability Public Funding Technological Automation	High Capital Efficiency Labor Productivity Eco-Friendly Niche Diverse Revenue Streams
Weaknesses	High Capital Requirements Regulatory Costs Logistical Complexity Dependency on External Funding	Low Margins Scalability Limitations Market Saturation Capital Constraints.
Opportunities	Growing Demand for Sustainable Energy Partnerships with Municipalities Regulatory Push for Recycling	Expansion into New Markets Technological Innovation Sustainability Trends
Threats	Regulatory Uncertainty Market Competition	Biomass Availability Environmental Regulations Competition from Larger Firms

The Keltakangas Waste Station operates on a capital-intensive business model focused on wood waste processing and biogas production. Its main strength lies in its ability to leverage economies of scale, which allows the facility to reduce per-unit costs and achieve stable profitability. With long-term residue collection contracts and public funding from local municipalities and the government, the station enjoys financial stability. Moreover, the station benefits from high levels of technological automation, which reduces labor costs and enhances operational efficiency. However, the Keltakangas Waste Station faces challenges related to its high capital requirements, both in terms of initial investment and ongoing maintenance. Regulatory costs, particularly the compliance with the Biowaste Sorting Expansion in 2026, add further operational expenses. Additionally, managing waste collection and transportation across a large region presents logistical complexities, and the station is highly dependent on external funding, which makes it vulnerable to potential policy or funding changes.

Opportunities for the Keltakangas Waste Station include the growing demand for sustainable energy, especially biogas, which offers significant potential for expansion. The facility could further boost its growth by expanding services to other municipalities, capitalizing on the regulatory push for increased waste sorting and recycling. These trends could drive higher demand for the station's services.

Keltakangas is vulnerable to regulatory uncertainty, as changes in waste management or environmental laws could lead to increased operational costs or hinder growth. Additionally, market competition from other waste management firms or energy producers could pose a threat, especially if they offer alternative solutions or more competitive pricing.

For Koumet, its business model is resource-efficient, focusing on biochar production and sustainable forestry practices. One of its strengths is its high capital efficiency, which allows it to produce biochar with relatively low capital expenditure compared to other models. The company has also developed specialized machinery for willow harvesting, which improves labor productivity and reduces costs. By aligning with the increasing market demand for eco-friendly products, Koumet has positioned itself in an eco-friendly niche. The company benefits from diversified revenue streams, offering services such as timber harvesting and forest management alongside biochar production, which reduces risk and improves its financial stability. However, Koumet also faces challenges, particularly in terms of low profit margins from biochar production. Scaling up operations is limited by the need for a consistent biomass supply, as well as the time-intensive nature of harvesting willows. Additionally, there may be market saturation in the local biochar market, requiring the company to expand into new regions or offer additional products to scale successfully. While Koumet is capital-efficient, it may still face difficulties scaling operations without external investment to meet growing demand for its products.

On the other hand, Koumet has opportunities in expanding into new markets, particularly with the rising global interest in carbon sequestration and sustainable products. Technological innovation, such as advancements in harvesting equipment or biochar production technology, could improve scalability and reduce production costs. Additionally, increasing regulatory pressure for carbon neutrality and sustainability presents growth opportunities for biochar, as it can be used to meet environmental goals in various industries.

A major threat is the availability of biomass, as ensuring a consistent and cost-effective supply becomes more challenging as the demand for biochar increases. Additionally, stricter environmental regulations or changes in policies could negatively impact forestry practices and biochar production. Competition from larger firms or integrated supply chain players could also erode Koumet's market share, potentially limiting its ability to expand within the biochar market.

5.3. Strategic Scaling Pathways and Risk-Return Considerations

Implications for CEBMs vary depending on the chosen scaling strategies.

Financial risk is a crucial factor to consider, as different scaling approaches carry varying levels of risk and return. Conservative scaling presents a lower-risk approach with modest returns, making it a safer but potentially less profitable strategy. On the other hand, aggressive scaling offers the potential for higher returns but comes with significant financial and operational risks. A moderate scaling strategy provides a balance between these two extremes, offering growth potential while mitigating excessive risk exposure.

Economic sustainability is another key consideration in CEBM decision making. If the company prioritizes long-term economic sustainability over short-term gains, moderate scaling could be the preferred approach, ensuring steady growth without overextending resources. However, aggressive scaling, if well-executed, could lead to market disruption and establish a dominant industry position, making it a strategic choice for businesses seeking rapid expansion and competitive advantage.

Resource allocation plays a fundamental role in executing any scaling strategy. CEBMs must effectively distribute capital, labor, and technology based on the chosen approach. Aggressive scaling often necessitates securing additional funding, enhancing workforce capabilities, and optimizing processes to handle rapid expansion. In contrast, conservative scaling is likely to focus on improving operational efficiencies and maximizing existing resources without significant new investments.

Strategic focus must also align with the broader corporate objectives. Whether the goal is to achieve market leadership, maintain profitability, or expand into new markets, CEBM must ensure that scaling strategies are in sync with the company's long-term vision. Each approach affects how resources are allocated, operational priorities are set, and risk management strategies are developed.

The implications for CEBM will vary depending on the scaling scenario. The key takeaway is that each approach must carefully balance revenue growth with operational risks to ensure that the company is well-positioned to seize market opportunities while maintaining financial stability and long-term sustainability.

This study contributes to advancing the theoretical understanding of CEBMs by illustrating how sector-specific characteristics—such as biomass dependency, regulatory complexity, and capital intensity—affect scalability strategies. Unlike generalized models, this paper provides a nuanced framework for comparing aggressive, moderate, and conservative growth in forest-based bioeconomy sectors. It introduces the concept of "Scalability Path Dependency," where organizational strategy is shaped not only by financial metrics but also by environmental alignment and resource logistics. These insights extend the literature on CEBMs by offering an integrated perspective that connects operational decisions with systemic sustainability goals, providing a replicable template for other regions and sectors transitioning toward circularity.

5.4. Theoretical Contribution: Scalability Path Dependency (SPD)

The SPD framework emerges from a fundamental insight observed in forest-based CEBMs: as these models scale, they tend to lose the flexibility that initially enabled innovation. This loss of flexibility is not random but shaped by the emergence of self-reinforcing feedback loops—such as network effects, infrastructure investment, economies of scale, or regulatory alignment—that constrain future strategic choices. What begins as a landscape of multiple feasible configurations gradually funnels into a dominant trajectory. SPD thus conceptualizes scalability not as a neutral or purely growth-oriented process but as one structured by early decisions that generate long-term constraints. To capture this dynamic, this study introduces the SPD "funnel model".

Figure 5 offers a conceptual visualization of the Scalability Path Dependency (SPD) framework, which emerges from empirical insights into forest-based circular economy business models (CEBMs). These models, though innovative and flexible in early stages, tend to lose that flexibility as they scale. The SPD framework explains this dynamic not as accidental, but as shaped by self-reinforcing mechanisms—such as infrastructure investments, network effects, economies of scale, and regulatory alignment—that progressively constrain future strategic options.

The funnel-shaped model illustrates this core insight. On the left, the wide mouth of the funnel represents a phase of high strategic diversity. Early in their lifecycle, forest-based and other circular models can explore a wide range of configurations—different technologies, value chains, governance structures, and market approaches. This phase is marked by experimentation, limited infrastructure dependency, and often, public support.

As scaling begins, models enter the narrowing portion of the funnel. Reinforcing mechanisms, while essential for growth and consolidation, also begin to reduce strategic flexibility. Each choice—be it investment in specific technologies or alignment with existing regulations—strengthens a particular scaling trajectory, making alternatives increasingly costly or unfeasible. This process reflects Arthur's [42] theory of increasing returns and Pierson's [43] notion of institutional entrenchment: early decisions accumulate into dominant pathways that shape long-term outcomes.

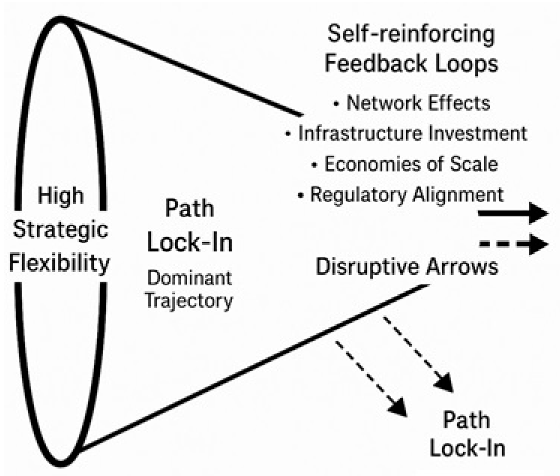

Figure 5. The SPD "funnel model".

Toward the right end of the funnel, this dynamic can result in path lock-in, where only a few model variants remain viable. While this may lead to positive alignment with circular goals, it can also result in entrenchment within linear or suboptimal regimes, depending on how the scaling trajectory evolves.

Importantly, Figure 5 also includes breakout arrows extending outward from the funnel. These symbolize the possibility of disruptive interventions—such as technological innovations, radical policy shifts, or cross-sector partnerships—that can destabilize existing regimes and re-open strategic space. This aspect draws from Geels' [44] multi-level perspective on sustainability transitions, highlighting that SPD is not deterministic. Though path dependency narrows options, windows for transformation remain.

Overall, the SPD funnel model serves as a diagnostic tool for understanding how forest-based CEBMs—and by extension, other circular models—evolve over time. It reveals the tension between the scaling benefits provided by reinforcing mechanisms and the strategic constraints they impose. By making visible both the risks of lock-in and the levers for renewal, the model supports more intentional, adaptive strategies for sustainable scale-up.

5.5. Empirical Validation of SPD: Case Applications

The empirical findings discussed in Section 4 validate the relationships in the SPD framework, illustrated in Figure 5. The SPD model was developed a priori, drawing from established theoretical foundations such as Arthur's theory of increasing returns, Pierson's concept of institutional entrenchment, and Geels' framework on sustainability transitions. It was designed to explain how the scalability of CEBMs in the forestry sector evolves over time. The model proposes that businesses start with high strategic flexibility, but, as decisions are made and self-reinforcing mechanisms such as infrastructure investment, regulatory alignment, and economies of scale accumulate, the available strategic options narrow. This progression is represented metaphorically as a funnel, in which the broad mouth signifies openness and diversity in early stages, while the narrowing shape illustrates the increasing constraints over time. Arrows piercing the funnel represent the potential for disruption—whether from technological innovation, regulatory shifts, or new partnerships—that may reopen the strategic landscape and offer alternative pathways.

The SPD model was constructed as a conceptual tool to analyze and interpret how CEBMs scale and evolve, and it was later applied to the case studies of Keltakangas Waste Station and Koumet to test its relevance and explanatory power. These case studies not only validate the framework by showing its correspondence with real-world patterns but also help refine it through the richness of their contrasting contexts. Keltakangas exemplifies a clear case of path dependency. In its early stages, the company experimented with multiple technologies, waste streams, and partnerships, supported by public subsidies and a relatively unconstrained strategic environment. This phase corresponds to the wide opening of the funnel, where flexibility is high. As the project expanded, however, substantial investments in infrastructure and automation—along with tightening regulatory expectations—anchored the business to a particular trajectory. A regression analysis identified Net Profit Margin as the main predictor of Return On Equity (ROE), highlighting the increasing importance of financial optimization as a driver of scalability. This progression closely mirrors the narrowing funnel and illustrates how initial flexibility gives way to increasing rigidity. The risk of lock-in, as predicted by the SPD framework, is present in Keltakangas' heavy reliance on specific infrastructure and business model configurations. Nonetheless, potential disruptors—such as changes in regulation (e.g., bio-waste sorting mandates) and new market incentives (e.g., carbon credits)—could reopen strategic space and allow for future adaptation.

Koumet, in contrast, presents a less linear but equally illustrative application of the SPD model. The company's development followed a flexible and exploratory path, evolving from timber extraction to a diversified circular business that includes biochar production, sustainable forestry, and specialized tree services. This initial phase, rich in experimentation with new technologies like willow harvesting and in exploring niche markets such as carbon sequestration and gardening, corresponds to the broad mouth of the funnel. As Koumet scaled, certain reinforcing mechanisms emerged—such as investment in pyrolysis technology and partnerships with local subcontractors—but the narrowing of strategic options was less pronounced than in Keltakangas. Interestingly, the regression analysis did not find any strong financial predictors of scalability, suggesting that Koumet's growth depends more on ecological and operational variables than on financial efficiency. This distinction refines the SPD model by emphasizing that different types of circular forestry models may experience varying forms and degrees of path dependency. In Koumet's case, the risk of lock-in arises not from infrastructure per se but from dependence on specific feedstocks and niche markets, which may limit adaptability if external conditions shift. However, similar to Keltakangas, Koumet also benefits from potential disruptive forces—especially internal innovation and the possibility of entering new sectors such as sustainable agriculture or water filtration—which could open new pathways for growth and transformation.

The comparative insights from these two cases serve to validate the SPD framework in its core logic—highlighting the dynamic interplay between early flexibility, self-reinforcing mechanisms, and the narrowing of strategic space—while also enriching it. Keltakangas demonstrates a more linear and finance-driven path dependency, whereas Koumet reflects a more fluid and operationally influenced trajectory. Both cases confirm the relevance of the funnel metaphor and the importance of identifying both the mechanisms that reinforce specific paths and the potential interventions that can disrupt them. Ultimately, the SPD model proves to be a robust interpretive tool, capable of accommodating the complexity and diversity inherent in circular business models in the forestry sector.

5.6. The Scalability Matrix: A Diagnostic Tool

Building on this conceptual foundation, the SPD framework is further operationalized through the development of a Scalability Matrix for Circular Business Models (Figure 6). This matrix integrates three dimensions critical to sustainable growth: financial scalability, ecological alignment, and institutional/infrastructural fit. The vertical axis measures financial capacity through conventional indicators like ROE or asset efficiency. The horizontal axis captures the degree of structural sustainability, including circularity, policy compatibility, and infrastructural embeddedness. This dual-axis approach generates four quadrants—Resilient Integrators, Profit-Centric Lock-ins, Ecological Pioneers, and Stalled Experiments—each representing a different expression of SPD in action.

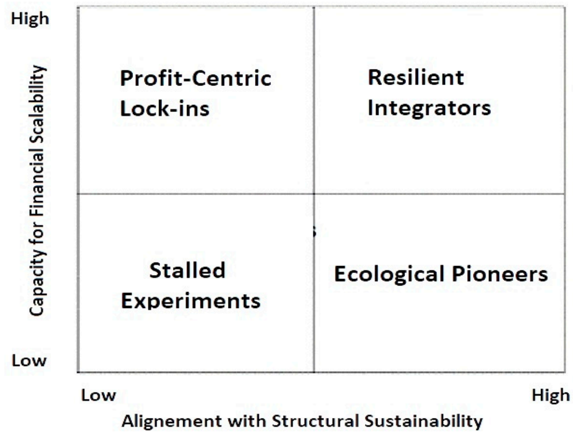

Figure 6. Scalability path dependency matrix for circular business models: integrating financial, environmental, and institutional dimensions.

The value of this matrix lies in its ability to classify business models not only by their current performance but also by the structural dynamics that shape their scaling trajectories. The vertical axis, "Capacity for Financial Scalability," captures traditional business performance indicators such as Return On Equity, operating margin, and asset efficiency. These measures indicate a model's potential to grow through market dynamics. However, financial strength alone does not guarantee sustainable scaling. The horizontal axis, "Alignment with Structural Sustainability," addresses this by integrating the environmental and institutional dimensions—especially the role of infrastructure, regulation, and public policy. Together, these axes form a matrix where four strategic positions emerge, each representing a distinct form of SPD.

In the top right quadrant, "Resilient Integrators" are models that combine financial viability with strong structural alignment. These businesses often benefit from supportive regulatory regimes, stable infrastructure, and circular practices embedded in their operations. A key example is the Finnish case of Keltakangas, which demonstrates how institutional lock-ins—such as clear regulation and public investment—can actually reinforce rather than hinder sustainable scaling. This represents a positive SPD, where institutional and financial feedback converge to sustain growth.

By contrast, the top left quadrant houses the "Profit-Centric Lock-ins." These are financially profitable models that remain structurally misaligned with circular economy principles. They may operate efficiently in the short term but rely on outdated infrastructure, exploit regulatory gaps, or perpetuate linear production logics. These models embody a negative SPD, where financial strength reinforces unsustainable practices, creating barriers to meaningful transformation.

The bottom right quadrant, "Ecological Pioneers," includes models that are environmentally and institutionally innovative—often well-aligned with circular economy ideals—but financially fragile or overly dependent on niche support. These may be driven by community values, policy pilots, or innovation grants. Koumet exemplifies this category, where the SPD remains unstable: the structural conditions are promising, but financial weaknesses inhibit scaling and resilience.

Finally, the "Stalled Experiments" in the bottom left quadrant are models that lack traction on all fronts. They may be early-stage ventures, idealistic prototypes, or under-resourced social enterprises. Without financial capacity or institutional backing, these models often remain confined to small niches or eventually fade. They reflect a blocked SPD, where no reinforcing mechanisms exist to push the model forward.

Crucially, this framework is theoretically grounded in the foundational literature—Arthur's [42] theory of technological lock-in, Pierson's [43] path dependency in institutional evolution, and Geels' [44] multi-level perspective on socio-technical transitions. These works clarify how structural forces and early decisions interact to shape long-term trajectories. But the SPD framework advances this body of theory by incorporating newer contributions from transition studies, particularly Wearne et al. [45] and Chlebna and Suitner [46]. These scholars emphasize the importance of reflexive system design, regional institutional dynamics, and environmental lock-ins—highlighting how circular innovations interact with and are often constrained by local governance structures, ecological limits, and infrastructure path dependencies. Their insights enrich SPD by anchoring it in real-world systems and by demonstrating how lock-ins can be more than technical or economic—they can be environmental and institutional as well.

By integrating these contributions, SPD emerges not just as a theoretical abstraction, but as a practical and diagnostic framework for analyzing the conditions under which circular business models scale, stagnate, or shift course. The funnel model and matrix together illuminate the temporal and structural mechanisms at play during the growth of CBMs, showing how reinforcing loops can both hinder and enable sustainable transitions. Importantly, SPD also offers strategic leverage points: it identifies where targeted interventions—whether policy-driven, infrastructural, or financial—might overcome systemic inertia and help circular models move toward resilience.

To sum up, the SPD framework captures the complex interplay of time, structure, and agency in circular business model scaling. It explains why promising innovations often struggle to move beyond pilot phases and how entrenched socio-technical regimes resist transformation. By combining foundational theories with recent transition research and visual tools like the funnel and matrix, the framework supports both analytical clarity and practical application—making it a versatile instrument for researchers, policymakers, and entrepreneurs alike who aim to navigate the challenges of sustainable scalability.

6. Conclusions

This study investigates the scalability and potential of circular economy business models (CEBMs) in the Kouvola region, focusing on two distinct case studies: Keltakangas Waste Station and Koumet. Both companies present innovative approaches to sustainable resource use, addressing key areas of the circular economy—waste valorization and forest residue conversion—while contributing to regional sustainability goals. Keltakangas, with its focus on biogas production from waste, and Koumet, which transforms forestry residues into biochar, represent different facets of the bioeconomy and the broader transition to sustainability.

The primary research question of this study focused on the scalability of CEBMs in the bioeconomy sector, specifically examining how different scaling strategies—conservative, moderate, and aggressive—affect financial sustainability, resource allocation, and overall environmental impact. This study found that both Keltakangas and Koumet could benefit from a moderate scaling approach. This strategy offers a balance between growth and operational efficiency, ensuring long-term sustainability while capturing significant growth opportunities.

Regarding the hypotheses tested, this study confirms that scaling strategies directly influence the economic outcomes and operational efficiency of CEBMs. The hypothesis suggesting that conservative scaling offers financial stability but limits market expansion is validated in the case of Keltakangas, where gradual growth is linked with steady profitability and low risk. The hypothesis that aggressive scaling involves high capital investment and increased financial risk is supported by the challenges faced by both companies, especially Keltakangas, where large infrastructure investments pose potential financial strains. Lastly, the hypothesis that moderate scaling aligns with sustainability goals while managing financial risk is affirmed, especially in the case of Koumet, where resource efficiency and market expansion in niche areas present a more feasible growth trajectory.

The findings of this study emphasize the importance of strategic decision making in scaling CEBMs. For Keltakangas, large-scale infrastructure investments, especially in waste processing and biogas conversion, require the careful management of operational costs and regulatory compliance. The company's long-term viability depends on maintaining steady investments and strengthening strategic partnerships, particularly with local municipalities and external stakeholders. In contrast, Koumet's smaller-scale, resource-efficient approach highlights the potential of niche markets and innovative technologies, such as specialized willow harvesting machines, to scale operations without overextending resources. However, Koumet must overcome challenges related to biomass supply and production costs to expand further into new markets.

This study underscores the role of regulatory frameworks and technological advancements in shaping the scalability of these models. Both companies rely heavily on regulatory incentives—such as biowaste sorting mandates for Keltakangas and carbon sequestration benefits for Koumet—to fuel growth and overcome operational barriers. These frameworks play a critical role in ensuring that scaling efforts align with national sustainability goals, such as Finland's renewable energy transition and carbon neutrality targets.

This study is limited by its regional focus and reliance on historical financial projections, which may not be universally applicable to all CEBMs. Future research could expand to include a broader range of case studies across different regions and sectors, enabling a deeper understanding of the scalability of circular economy models in diverse contexts. Additionally, examining the long-term impacts of scaling on resource efficiency, environmental sustainability, and financial stability will be critical for further validating the findings. Investigating the role of public–private partnerships, technological innovations, and policy developments in facilitating or hindering the scaling of CEBMs could provide further insights into best practices for overcoming the challenges identified in this study.

In conclusion, this study highlights that moderate scaling strategies present the most balanced approach for both Keltakangas and Koumet, ensuring sustainable growth while managing financial risks and operational complexities. The strategic alignment with broader corporate goals, alongside the necessary regulatory support and technological advancements, will be key to their continued success in the circular economy.

Crucially, this research introduces the concept of Scalability Path Dependency, arguing that CEBM scalability is not a linear or purely financial process but is path-dependent on ecological conditions, infrastructural readiness, and institutional support. While the empirical findings are rooted in the Finnish forestry context, the SPD framework offers a generalizable tool for understanding scalability dynamics across circular economy sectors—including energy, agriculture, and waste management. This theoretical contribution advances the field by offering a multidimensional framework for assessing CEBM growth trajectories, with practical relevance for businesses, researchers, and policymakers alike.

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Appendix A. Robustness Check Using Extended Lasso Regression

To assess the robustness of the Lasso model, we conducted an extended regression by adding two financial indicators from Orbis not previously included: EBITDA Margin and Asset Turnover Ratio. The objective was to test whether the original model's explanatory structure would remain stable when new indicators of operational profitability and efficiency were introduced.

Keltakangas Waste Station (NACE 3821)

In the baseline model, only Net Profit Margin was selected (coefficient: 0.0328), confirming its central role in explaining ROE. After including EBITDA Margin and Asset Turnover Ratio, the extended Lasso model yielded the following:

Indicator	Coefficient
Net Profit Margin (%)	0.0319
EBITDA Margin (%)	0.0062
Asset Turnover Ratio	0.0000
All Others	0.0000

The results show that Net Profit Margin remains the dominant driver of ROE, with a negligible change in magnitude. EBITDA Margin was selected but with a very small coefficient, indicating limited additional explanatory power. Asset Turnover was not selected, reinforcing the conclusion that operational scale and capital structure play a minor role in this firm's ROE. Overall, the model remains stable, supporting a margin-focused circular economy strategy for Keltakangas.

Koumet (Silviculture, NACE 0220)

The original Lasso regression for Koumet returned very low coefficients for all variables, suggesting no strong financial predictor of ROE. The extended model returned the following:

Indicator	Coefficient
Net Profit Margin (%)	0.0073
EBITDA Margin (%)	0.0048
Asset Turnover Ratio	0.0000
Gross Profit Margin (%)	0.0035
Productivity (Rev/Emp)	−0.0079
Solvency Ratio (%)	−0.0038
All Others	0.0000

As before, no variable stands out as a dominant explanatory factor. The inclusion of EBITDA Margin resulted in a small coefficient, but it did not meaningfully enhance the model's explanatory power. Asset Turnover again showed no significance. These findings confirm that ROE in Koumet is likely shaped by non-financial drivers, such as ecological factors, regulatory incentives, or long-term asset dynamics inherent in the forestry sector.

The inclusion of EBITDA Margin and Asset Turnover did not materially alter the structure of either model. In both cases, Lasso confirmed the stability of the original findings:

- In Keltakangas, profitability—particularly at the net margin level—remains the key driver of ROE.
- In Koumet, financial indicators continue to show weak explanatory power.

A preliminary check confirmed no severe multicollinearity among variables, ensuring that the selection process reflects genuine explanatory value rather than redundancy. These results reinforce the robustness of the original models and support the conclusion that financial strategies should be tailored to sector-specific performance dynamics.

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