RESEARCH ARTICLE

RAE: Revista de Administracao de Empresas

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Beyond growth: how scaling cleantech firms drives circular economy

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Received 21 December 2025
Accepted 22 December 2025

Abstract

Purpose – The paper aims to investigate how scaling activities – specifically acquisitions, financing, innovation and digitalization – foster the development of circular economy (CE) strategies within digital cleantech firms. The research also proposes a conceptual model that asserts how scaling activities in digital cleantech firms facilitate and accelerate CE strategies.

Design/methodology/approach – The study uses a qualitative, multiple-case study approach involving 12 born-digital cleantech firms in Brazil. Data was collected through 18 semi-structured interviews with senior executives and supplemented by documentary analysis and secondary data for triangulation.

Findings – The findings indicate that scaling activities directly structure the adoption of circular practices: acquisitions facilitate access to sustainable technologies; financing and innovation drive environmental projects and low-impact solutions; and digitalization optimizes resource use through operational flexibility. Furthermore, digital capabilities are identified as a crucial antecedent for embedding CE into scaling strategies.

Research limitations/implications – The study is limited by its focus on infrastructure-related cleantech firms within the Brazilian regulatory and technological context. Future research should explore different geographic regions and industries to enhance the generalizability of the proposed conceptual model.

Practical implications – The research offers offer a roadmap for cleantech firms to assess their digitalization competencies, identify technological market pathways and generate positive externalities for the environment, economy and society. It also provides insights for policymakers to design institutional environments that encourage environmental, social and governance-aligned growth.

Social implications – The research contributes practically by offering insights for firms and policymakers seeking to promote sustainability through digital technologies.

Originality/value – The paper contributes to the literature by linking scaling and CE strategies in digital cleantech firms. It provides a conceptual model that explains how digital scalability can transition firms toward a circular model, moving beyond a simple growth focus to include sustainable value creation.

Keywords Scalability, Scale-up firms, Circular economy, Strategy, Cleantech

Paper type Research paper

Além do crescimento: como a escalabilidade DE empresas DE tecnologia limpa impulsiona a economia circular

Resumo

Objetivo – O artigo investiga como as atividades de escalabilidade – especificamente aquisições, financiamento, inovação e digitalização – fomentam o desenvolvimento de estratégias de economia circular (EC) em empresas digitais de tecnologia limpa. A pesquisa também propõe um modelo conceitual que

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RAE: Revista de Administracao de Empresas
Vol. 66 No. 1, 2026
pp. 1-18
e2026008
Emerald Publishing Limited
0034-7590
DOI 10.1108/RAE-03-2026-0016

demonstra como as atividades de escalabilidade em empresas digitais de tecnologia limpa facilitam e aceleram a adoção de estratégias de EC.

Desenho/metodologia/abordagem – O estudo emprega uma abordagem qualitativa de múltiplos casos, envolvendo 12 empresas de tecnologia limpa nativas digitais no Brasil. Os dados foram coletados por meio de 18 entrevistas semiestruturadas com executivos seniores, complementadas por análise documental e dados secundários para fins de triangulação.

Resultados – Os resultados indicam que as atividades de escalabilidade estruturam diretamente a adoção de práticas circulares: aquisições facilitam o acesso a tecnologias sustentáveis; financiamento e inovação impulsionam projetos ambientais e soluções de baixo impacto; e a digitalização otimiza o uso de recursos por meio da flexibilidade operacional. Além disso, as capacidades digitais são identificadas como um antecedente crucial para a incorporação da EC às estratégias de escalabilidade.

Limitações/implicações da pesquisa – O estudo é limitado por seu foco em empresas de tecnologia limpa ligadas à infraestrutura, dentro do contexto regulatório e tecnológico brasileiro. Pesquisas futuras devem explorar diferentes regiões geográficas e setores industriais para ampliar a generalização do modelo conceitual proposto.

Implicações práticas – A pesquisa oferece um roteiro para que empresas de tecnologia limpa avaliem suas competências de digitalização, identifiquem caminhos tecnológicos e de mercado e gerem externalidades positivas para o meio ambiente, a economia e a sociedade. Também fornece subsídios para que formuladores de políticas públicas criem ambientes institucionais que incentivem o crescimento alinhado aos princípios ESG.

Originalidade/valor do artigo – O estudo contribui para a literatura ao conectar estratégias de escalabilidade e de EC em empresas digitais de tecnologia limpa.Apresenta um modelo conceitual que explica como a escalabilidade digital pode conduzir as empresas a um modelo circular, indo além de um foco exclusivo no crescimento para incluir a criação de valor sustentável.

Palavras-chave Escalabilidade, Empresas escaláveis, Economia circular, Estratégia, Cleantech
Tipo de artigo Trabalho de pesquisa

How to cite this article:
Noronha MESD, Cahen F, Almeida LF. Beyond growth: how scaling cleantech firms drives circular economy RAE: Revista de Administracao de Empresas 2026;66:e2026008. https://doi.org/10.1108/RAE-03-2026-0016

Introduction

Scalability has been described as the expansion and growth of entrepreneurial firms (Monaghan et al., 2020), which has attracted the attention of startup founders, investors and stakeholders worldwide. In this study, we adopt the mathematically validated definition of scaling proposed by Bohan et al. (2024, p. 3), which defines it as "a time-limited process in which the size of a business grows exponentially, i.e. increases in proportion over time." This definition distinguishes scaling from other forms of business growth. Digitalization – the use of digital technologies, such as the internet, cloud computing, mobile platforms and artificial intelligence (AI) to create new business strategies (Amankwah-Amoah et al., 2021) – has accelerated the conditions that enable scalability, making it an increasingly widespread phenomenon across various sectors. Scaling businesses, or scale-ups, expand their operations by leveraging digital infrastructures (Huang et al., 2017). This enables them to grow much faster than traditional product-based ventures (Piaskowska et al., 2021). They also tend to move through organizational cycles more rapidly, achieving cost reductions that are proportional to their growth (Piaskowska et al., 2021; Reuber et al., 2021; Mihailova, 2023). Strategies for scale-ups differ from growth strategies of nascent businesses and mature firms. A distinctive characteristic is the speed of growth – scaling is a period of extremely rapid growth, with annual increases over 40% (World Economic Forum, 2016), a rate that is significantly higher than the 20% rate that normally denotes high growth in the number of employees and business volume in mature firms [Organization for Economic Cooperation and Development (OECD), 2007]. For scale-ups, the user base, data packages and digital infrastructure, combined with highly specialized services, are central to the scaling strategy, rather than traditional growth measures such as sales levels, profitability and market share (Huang et al., 2017).

In the context of digitalization and scalability in entrepreneurial ventures, the term "cleantech" refers to emerging clean solutions that leverage digital technology (Shakeel, 2021). Cleantech firms use digital technologies to develop solutions in key infrastructure sectors such as energy, transportation and sanitation, aiming to promote the sustainable use of natural resources. (Suchek et al., 2021; da Silva, 2019; Linder & Williander, 2017). Our study focuses on "born-digital" cleantech firms, those that are digital from inception and use the internet for everything from product development to operations and delivery (Monaghan et al., 2020; Stallkamp et al., 2023). We examine how scaling activities foster circular economy (CE) strategies in digital cleantech firms. These firms offer alternative solutions aligned with CE principles, reducing customer costs while conserving energy and water as they scale and generate profit. Prominent examples of digital cleantech firms are Delfos Energy, Stattus4 and Nextron, enterprises that track water usage, monitor energy efficiency and facilitate access to clean and renewable energy through innovative funding and credit mechanisms, addressing both political agendas (Belitski et al., 2023; Leitão et al., 2024) and global sustainability goals (Suchek et al., 2021; da Silva, 2019; Linder & Williander, 2017).

Despite the growing relevance of cleantech firms, little is known about how they scale their businesses in the market (Cumming et al., 2016; Noronha et al., 2022). Owing to these firms' typical sustainability goals, their scaling process involves more than just exponential growth. It requires understanding how scaling reduces operational costs and supports the development of CE strategies (Nygaard, 2022; Leitão et al., 2024). Thus, this research poses the central question:

Q1. How do scaling activities foster the development of CE strategies in cleantech firms?

The study adopts a qualitative, multiple-case study approach with 12 cleantech firms and 18 interviews with senior executives. The research proposes a conceptual model based on four propositions that assert how scaling activities in digital cleantech firms facilitate and accelerate CE strategies. These scaling activities include acquisitions, financing, innovation and digitalization, which reduce operational costs and enhance CE expansion and effectiveness.

The research contributions to the recent literature on digital scalability are threefold. First, our study extends beyond Reuber et al. (2021) and Piaskowska et al. (2021), who discuss digital scalability but do not present the necessary antecedents for carrying out scalability activities or empirical evidence. Additionally, both studies recommended deepening research on scalability strategies, considering their social impact, the consequences of activities related to firms' digitalization and the antecedents to their scaling process. Second, we extend Piaskowska et al.'s (2021) work by incorporating the perspective of cleantech firms into the analysis of scaling strategies and the relationship between scaling activities and CE. Third, we bring practical insights on how to manage scalability. The findings may serve as a roadmap of key drivers for firms seeking to scale while implementing CE strategies. The findings may serve as a roadmap of drivers for firms that scale while implementing CE strategies. The study also contributes by enabling firms to define technology-based market routes and generate positive environmental, economic and social externalities.

Theoretical background

The selected theoretical lenses are at the intersection of two emerging research streams: the growing body of entrepreneurship literature that examines the strategies, growth and globalization of born-digital firms (Monaghan et al., 2020; Stallkamp et al., 2023), and CE studies, which focus on mitigating environmental impacts (Geissdoerfer et al., 2018; Kirchherr et al., 2017; Suchek et al., 2021; Zucchella & Previtali, 2019).

Scaling digital ventures and links to circular economy transitions

Scaling differs from growth. Growth refers more broadly to any increase in the business size. Penrose's (1995) theoretical framework on firm growth and resource allocation during a company's maturity has been widely applied to understand how businesses grow and perform. In this view, resource scarcity and value creation are central to growth, as they shape the firm's ability to replicate and generate innovations, especially amid rapid technological and digital change (Piaskowska et al., 2021). Scaling, on the other hand, is more precisely framed from a mathematical perspective. As Bohan et al. (2024) explain, scaling occurs when a business experiences repeated proportional increases in size. This process can be represented as an exponential function, where time is the exponent and "size" is measured by either inputs (e.g. number of employees) or outputs (e.g. revenue). Accordingly, scaling is defined as "a time-limited process in which the size of a business grows exponentially, i.e. increases in proportion over time" (Bohan et al., 2024, p. 39).

This distinction is particularly relevant in digital businesses, where scalability – characterized by a brief period of hypergrowth – challenges traditional views on growth and complexity (Piaskowska et al., 2021; Coad, 2018; Gupta et al., 2017; Ramadoss et al., 2018). This study focuses on "born-digital" firms, those that are digital from inception (Monaghan et al., 2020; Stallkamp et al., 2023) and use the internet for everything from product development to operations and delivery. They leverage digital infrastructures to achieve economies of scale, reduce operational costs and enable rapid international expansion (Monaghan et al., 2020; Mihailova, 2023; Adner et al., 2019). Born-digital firms interact instantly with global customer bases (Chui & Manyika, 2015) and create new and scalable digital business models in response to evolving market demands (Bresciani et al., 2018; Vaska et al., 2021).

To seize opportunities and gain a competitive advantage, scale-ups can engage in four key scaling-enabling activities: acquisitions, financing, innovation and digitalization (Piaskowska et al., 2021).

Acquisition activities help scale-ups overcome resource constraints. In particular, international acquisitions mean growth in new markets across countries and the acquisition of new organizational capabilities, including knowledge and value-creating skills to scale up the firm's operation. Thus, scaling through acquisitions can expand production opportunities (Penrose, 1995), contribute to innovation by a new source of knowledge and technologies and produce organic growth that helps firms overcome internal capability gaps (Piaskowska et al., 2021).

Financing activities are essential for scaling, as access to capital enables firms to rapidly invest in the resources and capabilities needed for exponential growth (Piaskowska et al., 2021; Nason & Wiklund, 2018). The firm's nature – its governance structure, stage of development and funding model – shapes how financial resources are mobilized and deployed throughout the scaling journey. Capital enables firms to quickly build operational capacities, expand teams and enter new markets. From this perspective, funding for attracting human resources is the most significant form of capital, enabling the design of strategies and plans, thereby bringing purpose to the firm (Piaskowska et al., 2021; Nason & Wiklund, 2018). Unlike gradual growth, funding plays a pivotal role as it drives other scaling activities such as innovation, acquisitions and digitalization. Without sufficient financial backing, companies struggle to scale up efficiently or sustain the momentum needed for exponential growth.

Innovation activities focus on creating, improving, or developing new technologies, products, services and business models that differentiate the business from its competitors (Piaskowska et al., 2021; Siegel et al., 1993). This scaling-enabling activity can be facilitated by internal innovation, leveraging specific capabilities and resources. Digital offers can be

easily replicated, and a scale-up's proprietary technological knowledge, often at the core of its business model, offers an opportunity to grow by exploiting its innovation at scale.

Digitalization activities enhance scalability by building efficient digital infrastructure, often relying on cloud computing to manage resources, integrate services and store and analyze user data without depleting resources (Nambisan et al., 2019). It represents the blending of the physical and digital realms, facilitated by technologies such as internet of things (IoT), computing capabilities, data analysis, machine learning, AI, smart devices, sensors and platforms (Gebauer et al., 2020; Ramadoss et al., 2018). Digital offers and processes are inherently flexible, allowing for easy adjustments, extensions and replication (Nambisan et al., 2019). As a result, firms that focus on digital offerings and have digitalized processes face lower costs when adjusting during the scaling phase and can integrate new activities more seamlessly (Piaskowska et al., 2021).

To define these four scaling activities, Piaskowska et al. (2021) examined scaling modes of 184 digital scale-ups, including unicorns and aspiring unicorns. They identified four distinct modes: network growers (firms that prioritize digitalization activities), organic innovators (firms that emphasize innovation), focused scalers (firms that concentrate on developing offerings for specific markets or industry segments by leveraging high-quality technologies) and constricted scalers (firms constrained by limited financial and human resources). The four scalability activities demonstrate how scale-up companies have transformed the way businesses operate.

The capacity for scalability of digital companies is partly because of their low distribution costs and strong network effects in their online markets (Giustiziero et al., 2023; Adner et al., 2019). Moreover, leveraging digital offers and their cost advantages is a key strategy for outperforming rivals and optimizing daily operations in scale-up companies. By leveraging digitalization, scalability activities can help reduce operational costs while promoting resource circularity, thus minimizing negative social and environmental impacts (Zucchella & Previtali, 2019). Recent research has highlighted the central role of digital technologies in optimizing resource use and advancing circularity goals (Centobelli et al., 2020; De Pascale et al., 2021; Suchek et al., 2021; Giustiziero et al., 2023).

The linear model, typical of modern industrial economies, has been frequently criticized for its inability to address the depletion of natural resources and the waste it generates. According to Kirchherr et al. (2017), CE is a viable alternative, proposing that material flows be closed to minimize waste. The Ellen MacArthur Foundation defines CE as a system aimed at maintaining the value of products, materials and resources in the economy for as long as possible while regenerating natural systems (Suchek et al., 2021). The transition to CE is urgent, given that the linear model is no longer sustainable in a world where resources are becoming scarce and environmental pollution is an increasing concern (da Silva, 2019; de Pascale et al., 2021). From da Silva's (2019) perspective, CE is not merely a new standard for sustainable business but also a direct response to resource crises and the environmental impact caused by linear production.

From a practical perspective, CE aims to reduce waste and maximize resource efficiency by closing material loops and reintegrating end-of-life products into the production cycle as inputs. This approach minimizes waste and transforms it into valuable resources, promoting the reuse and recovery of materials. The central idea is that "nothing is lost, everything is transformed," highlighting the importance of creating value from materials that would otherwise be discarded (Geissdoerfer et al., 2018; Kirchherr et al., 2017; da Silva, 2019; Zucchella & Previtali, 2019).

In this context, CE necessitates an innovative approach to product and service design, emphasizing durability, reparability and recyclability to minimize environmental impact

throughout the product lifecycle (Geissdoerfer et al., 2018; Suchek et al., 2021). Implementing CE also requires collaboration and integration among various stakeholders, including businesses, consumers and governments, where consumer education and engagement play a crucial role in the transition to a circular model (Becque et al., 2016). Internal collaboration (Barboza et al., 2022) and perspectives on resource allocation and dynamic capabilities are also central to adopting and implementing CE within the business strategic framework Leitão et al., 2024). Based on these prior studies, three categories are presented as central to the CE strategy:

First, the preservation and appreciation of natural capital involve controlling finite stocks and balancing renewable resources. This category encompasses land, forests, fossil fuels, minerals, fishing and other natural resources along with ecosystems that, through their functioning, provide essential goods and services to the economy (Barbier & Burgess, 2017; Barbier, 2021; da Silva, 2019). Finite natural resources are used to manufacture goods and services that can be recycled, renovated and reintegrated into the firm's daily operations. This reduces costs by maximizing the use of existing resources to generate products with lower environmental impact (Becque et al., 2016). Digital offerings, such as online platforms for resource tracking and reuse marketplaces, play an increasingly important role in enabling resource efficiency (Çetin et al., 2022).

Second, resource optimization involves improving manufacturing efficiency and extending material longevity to achieve the highest level of usefulness throughout the lifecycle (Linder & Williander, 2017; Barboza et al., 2022). Technical aspects, such as material selection, recycling processes, input shortages and availability of skilled labor, are central concerns (Suchek et al., 2021; da Silva, 2019). Reuse and remanufacturing are crucial for optimizing resources in manufacturing processes, as they enable circularity, thereby mitigating the environmental and societal impacts. Examples include companies investing in clean technologies of renewable energies, such as wind and solar and rethinking their production chains with a view to CE (Noronha et al., 2023; Geissdoerfer et al., 2018). Digital solutions, including predictive maintenance platforms and digital twin technologies, support these efforts by optimizing material flows and production processes (Soori et al., 2023).

Third, boosting system effectiveness involves identifying and excluding negative externalities associated with resource use. This includes efforts to prevent, reduce, or mitigate the negative impacts of manufacturing and service implementation processes. Negative externalities can include manufacturing waste, socio-economic impacts on communities, gas emissions into the atmosphere and other environmental harms caused by companies (Becque et al., 2016). Digital monitoring tools, IoT in manufacturing and data analytics solutions are increasingly deployed to track and reduce these externalities across value chains (Leitão et al., 2024).

Digital solutions and the broader digitalization process are increasingly linked to higher levels of corporate sustainability. As Suchek et al. (2021) emphasize, achieving sustainability and CE outcomes often requires strategic resource allocation and partnerships to develop digitally enabled products and services. Scalability activities further enhance this process by enabling the efficient use of digital platforms and digital capacity (Monaghan et al., 2020; Giustiziero et al., 2023; Noronha et al., 2023a) and lay the groundwork for more integrated and effective resource management.

Table 1 illustrates how the four scaling activities identified by Piaskowska et al. (2021) – acquisition, financing, innovation and digitalization – can be strategically aligned with the core categories of CE: preservation and appreciation of natural capital, resource optimization and system effectiveness. This integration highlights how each scaling activity can serve as a lever to implement and expand CE strategies within organizations and ecosystems. By

Table 1. Scaling activities and CE strategies

Scaling activities (Piaskowska et al., 2021)	CE strategies
Acquisition	Forge partnerships or acquire stakes in new or established ventures to access technologies that support preservation and appreciation of natural capital, resource optimization and system effectiveness
Financing	Explore alternative funding sources to support initiatives focused on preservation and appreciation of natural capital, resource optimization and system effectiveness, while reducing costs through efficient resource use
Innovation	Develop solutions or participate in online platforms for resource tracking and reuse marketplaces to enhance the preservation and appreciation of natural capital. Drive resource optimization through manufacturing innovations that extend material longevity and promote system effectiveness via eco-efficient design and processes
Digitalization	Leverage digital platforms for resource tracking and reuse to foster preservation and appreciation of natural capital. Use predictive maintenance and digital twin technologies for resource optimization and implement IoT, digital monitoring and data analytics to improve system effectiveness

mapping these connections, the table provides a practical framework for businesses and policymakers to understand how growth-oriented actions (scaling) can directly support sustainability goals.

The Circularity Gap Report, first published in January 2018 during the World Economic Forum in Davos, provides an annual assessment of the global state of the CE. This report aims to measure the level of circularity worldwide and offer strategic guidance for policymakers, businesses and civil society to accelerate the transition toward a more circular and sustainable economic model. Recent editions of the report have adopted a widely recognized taxonomy of circular resource strategies, originally developed by Bocken et al. (2016). This framework encompasses four integrated approaches: narrow (doing more with less), slow (extending the use of products and components), close (recycling materials) and regenerate (restoring and enhancing the natural environment). This classification has been extensively used to analyze CE practices across various firms, large corporations and specific sectors, including fashion, construction and renewable energy.

CE continues to evolve and primarily serves as a tool to advance sustainability by aligning social, environmental and economic objectives, rather than promoting a "post-growth" agenda (Kirchherr, 2022). Sustainability policies grounded in circularity principles – such as lifecycle extension, reduced resource consumption and ecological regeneration – enable the large-scale provision of sustainable products and reduce the risk of rebound effects in the CE (Kirchherr et al., 2023).

Method

The study adopted a deductive-inductive, in-depth case study method (Eisenhardt, 1989; Eisenhardt & Graebner, 2007), appropriate for the strategic nature of a firm's scalability, highly confidential information and the process-focused "how" questions of our research. The method also enables the exploration of subjective aspects and individual perspectives (Yin, 1994) within the cleantech sector. The strategy-process research provided the background to capture the scalability process and its relationship with CE.

Research setting and case selection

The research setting comprised born-digital cleantech firms. The definition of born-digital proposed by Monaghan et al. (2020) was adopted, referring to firms that offer exclusively digital products or services (i.e. no physical products) through a digital business model. For the definition of cleantech firm, three guiding pillars were considered:

(1) The incorporation of technologies that optimize the use of natural resources;

(2) The reduction of environmental and social impacts; and

(3) Innovation grounded in the renewability and circularity of resources (Cumming et al., 2016; Noronha et al., 2023).

At the intersection of these definitions, the criteria for selecting the case studies were:

- Being a born-digital cleantech firm in the process of scaling up; and
- Leveraging digital technologies in its operations and product and service development.

Both criteria limit These criteria limit the scope of the research on how digital solutions can scale the development of CE solutions.

Data collection

Primary data was obtained through semi-structured interviews from September 2021 to March 2023. Interviews conducted in 2021 and 2022 were followed up on at the beginning of 2023 to update information. There were 18 interviews at 12 cleantech firms. The selected companies have between 10 and 30 employees, with their headquarters in Brazil in the regions of São Paulo, Minas Gerais, Brasília and Rio de Janeiro. Our research encompasses the primary sectors of cleantech activity, including clean energy, energy efficiency, energy marketing and certifications, water treatment and management and urban mobility.

The interviewees were senior executives with an average of 20 years of experience working in cleantech firms. Those were the most qualified individuals to discuss their firms' scalability process. All interviews lasted between 60 and 90 min and were conducted in Portuguese, recorded and then transcribed for data coding. The saturation of repeated words in qualitative research measurements justified the number of interviews that comprised the selected sample (Guest et al., 2006). The interview protocol included two deductive analytical categories that emerged from the literature review:

(1) Scalability activities in digital companies: this category focused on the firms' activities aimed at fostering scalability;

(2) CE strategies: this category explored the CE strategies adopted by the firms. Table 2 shows the firms' profiles.

Data analysis

Three main steps were retained, along with standard data analysis procedures, in case-study research (Eisenhardt, 1989; Eisenhardt & Graebner, 2007). First, we examined the cases individually and coded the textual material according to previously established theoretical categories. We used content and documentary analysis for each case at that stage. Content analysis went through the following steps:

- Transcription of interviews;
- Pre-analysis, which required careful reading to identify relevant topics;

Table 2. Case details

Firms (12)	Foundation year	Scope of action
A	2019	Financial credit for implementing solar energy
B	2018	Trading renewable energy certificates
C	2020	Monitoring energy consumption, optimization and energy efficiency
D	2017	Trading solar energy
E	2019	Sanitation and water treatment
F	2018	Trading solar energy
G	2020	Energy and mobility
H	2019	Carbon capture
I	2017	Wind farm monitoring system
J	2018	Monitoring energy consumption, optimization and energy efficiency
K	2018	Digital consulting for reduction of energy consumption and platform of energy services
L	2019	Trading energy credits through blockchain

- Coding the units of analysis, grouped into categories; and
- Interpretation of the results and inferences based on the interviews (Bardin, 2016).

We used MaxQda software to organize data and to facilitate identifying and coding patterns and recurring topics. In addition, we employed documentary analysis to examine the documents and validate the reports transcribed and analyzed using the software (Bowen, 2009).

The coding process followed an abductive approach, drawing on the theoretical framework that includes two main concepts: scaling activities in digital companies and CE strategies. This process generated a set of codes that reflect the four scaling activities – acquisition, financing, innovation and digitalization – and the three CE categories – preservation and appreciation of natural capital, resource optimization and system effectiveness. Experts from the clean technology sector, academic researchers and the scientific literature used in the theoretical framework reviewed and confirmed the relevance and accuracy of these codes.

Second, we conducted a cross-case analysis by compiling data tables for each case and theoretical category, subsequently comparing cases across these categories to identify similarities and differences (Eisenhardt, 1989; Eisenhardt & Graebner, 2007).

Finally, for triangulation, we combined evidence from various sources, including internal documents, secondary data and external materials like reports, firms' press articles, official websites, CEOs' interviews and podcasts, which was crucial for enhancing the validity and reliability of our primary data and results.

Results and proposition development

Scalability activities and circular economy

Building on insights from the literature review and reinforced by our interviews, we qualitatively analyzed the four scaling activities – acquisition, financing, innovation and digitalization (Piaskowska et al., 2021). These activities not only enhance competitiveness and reduce costs but also align with CE strategies. The results demonstrate the direct impact of scaling activities on CE strategies, as illustrated by selected case studies (Table 3). Table 3 also includes illustrative quotes that highlight the connection between these activities and their practical outcomes.

Table 3. Quotes and scaling activities and their impact on CE

Scaling activities	Impacts on CE	Quotes
Acquisition activity	Acquisition activities ensure the incorporation of digital and technological capabilities through IoT and AI to track pollution and gas emissions, water waste and optimize production processes, avoiding waste of resources	"Our company has a completely digital approach to customer communication. This is done at a low internal cost. We are scaling up the business with a small team and, at the same time, providing valuable information to our (B2B) customers based on IoT technology for monitoring the energy consumption of solar plants" (Interviewee 5)
Financing activity	Facilitating credit and financing through the "financing activity" for cleantech firms allows the development of clean energy technologies, such as wind and solar, to be scaled up, reducing pollutant emissions and managing natural resources in a renewable and reusable way. Obtaining financing reduces the costs of these technologies and makes energy affordable and accessible to society	… "We are doing project finance, which is project financing on a retail scale. And to do this efficiently, it's necessary to reduce transaction costs to the point where operations are viable. The system is financed 100% with immediate savings, because the installment is smaller than the savings. The client generates sustainable and social impact, and after paying off the financing, has free energy for over 20 years" (Interviewee 5)
Innovation activity	innovation activities allow us to identify technologies and ways of wasting finite resources, making production processes more efficient. Energy efficiency and water reuse and treatment are conditions that promote CE	"Our business focus is sanitation, providing solutions for water saving. We have a fluid system whose mission is to improve the efficiency of water distributors by fighting losses. We have a mobile fluid system that scans the city for potential leakage points." (Interviewee 6)
Digitalization activity	The use of digital sensors, digital twins and AI anticipates information on market prices, pollution, climate predictability and energy consumption, reducing internal and external technology costs and expanding the adoption of new renewable energy sources in national electricity systems	… "Digital, on the One hand, provides the agility that people are looking for, right? Besides cost savings. I believe that One of the main reasons is not just speed, but lower costs in terms of attracting and serving customers. In addition, the process will be more democratic and will allow greater production, distribution, and trading of clean, renewable energy. The more digitalized the process, the more economical it will become" (Interviewee 2)

We present four theoretical propositions regarding how scaling activities foster the development of CE strategies.

By acquiring clients, suppliers, or competitors, the company can enter new markets and expand abroad, gaining knowledge, capabilities and skills that can then be leveraged and used for scaling. Our cases reinforce the notion that acquisition activity contributes to organic growth by solving resource and capability constraints (Piaskowska et al., 2021). In our cases, acquiring solar power generation plants to sell energy quotas was crucial to the strategic growth and scalability of the business. After acquisitions, scalability grows organically, achieving high digital capillarity on platforms that enable real-time management of energy and water consumption, minimize transaction costs and reduce operational and financial risks, ultimately creating a customized service. Thus, we propose the following:

P1. Acquisitions support CE by enabling access to technologies and partnerships that enhance environmental stewardship and operational efficiency.

Interviewees stated that their scaling period was highly associated with financing activities. Attracting and accessing investors and other sources of capital were critical to the company's scaling, in line with Piaskowska et al. (2021) and Nason & Wiklund (2018). In our cases, financing activities were reported in cleantech firms as crucial for implementing a strategy that leverages regulatory gaps to facilitate the commercialization of solar energy or the financing of renewable energy projects, thereby scaling up other projects, as stated by Interviewee 5 in Table 2.

While financial resources enable scale-up firms to fund their scaling period, innovation activities are crucial for competitiveness in terms of internal development and the improvement of a company's technological products or processes, thereby differentiating the firm in the market. Because digital offers are easily replicated, the innovation and proprietary technological knowledge of a scale-up provide a more defensible and sustainable source of competitive advantage (Piaskowska et al., 2021). The report on the Brazilian Cleantech Industry [Fundação Getulio Vargas (FGV), 2019] reinforced the finding that innovation activities are essential for defining companies' costs when dealing with institutions and governments that adopt cleantech solutions, finding alternatives for smart cities, reducing waste of natural resources and even finding ways to finance new social projects. These innovative products and services bring scalable growth for cleantech firms in their markets.

Financing and innovation activities play a central role in enabling scalable growth for cleantech firms. Financing emerges as a critical driver, not only for securing capital but also for structuring CE strategies that leverage regulatory opportunities – such as those in the solar energy sector – to scale operations efficiently. These financial strategies reduce transaction costs, enable customers to adopt sustainable solutions with immediate economic benefits and reinforce alignment with CE principles. Innovation is also essential, particularly in navigating institutional and governmental frameworks, developing smart city solutions, minimizing resource waste and supporting the creation of socially impactful projects. Innovative products and services allow cleantech firms to differentiate themselves and expand within their markets, confirming their strategic importance for long-term competitiveness and environmental impact. Thus, we propose the following:

P2. Financing and innovation scaling activities ensure that CE initiatives are economically viable, supporting the development of new products, services and processes that reduce environmental impact and extend the lifecycle of materials.

According to the interviewees, the digitalization activity revealed that companies that scale up through AI and IoT solutions can create specialized businesses to generate socio-economic benefits. These companies offer products and services that use renewable energy, conserve water and incorporate energy-saving systems, along with financing lines that specialize in environmental and inclusion solutions. Hence, digitalization enables the efficient use of technology and the management of user information without depleting resources. In the interviewed firms, digitalization minimizes their impact on natural resources, diluting costs through specific technologies that make businesses more efficient in using finite resources. The interviewees also reported that the use of IoT and Big Data in the disposal and reverse logistics of materials can be better mapped, resulting in minimized costs and increased scale in customization for various clients (Table 2 – Interviewees 5 and 6).

All interviewed cleantech firms are born-digital – created within the digital scope, with a large ability to reach customers and implement resources and processes, seeking agile and low-cost production through automated procedures enabled by digitalization (Monaghan et al., 2020). The inherent nature of being a born-digital company enables effective technological management in digital environments. Digitalization is a key driver of scalability for born-digital firms, whereas traditional companies with physical products and manufacturing processes that adopt these technologies lack the agility to scale their business (Piaskowska et al., 2021). Our study revealed that digital cleantech firms use digital technologies to scale their operations, serving a larger customer base while expanding their reach and enhancing their capacity to deliver products and services. It has roots in economic competition, where new digital technological advances are seen as opportunities and solutions for companies (Cahen & Borini, 2020).

The interviewed entrepreneurs described intense efforts to build digital capabilities. Digital cleantech firms develop and accumulate digital capabilities to carry out scalability activities and are more familiar with technologies that enable the creation of sustainability and resource-saving strategies (Interviewee 2 – Table 2). These firms enter the market in search of a competitive advantage to achieve scalability while developing digital capabilities (Monaghan et al., 2020). Capabilities refer to a company's ability to create and use resources to perform activities that sustain its operations and generate income (Cahen et al., 2025). The cleantech industry has operated with high levels of digitalization and technology since its inception, seeking clean technology solutions that preserve natural resources, reduce costs and use AI and IoT to monitor the consumption of water, energy and other resources (Gebauer et al., 2020).

Digital capabilities have been extensively discussed in the literature on entrepreneurship (Adner et al., 2019; Cahen & Borini, 2020; Cahen et al., 2025) and are defined as the ability to integrate Information and Communication Technology skills, technological capabilities and digital literacy. They emerge from a competitive economic environment in which digitalization and digital advancements offer strategic opportunities for businesses. Firms with a digital foundation shape their strategies from the outset with capabilities that ensure agility in delivering content and services to a constantly evolving market. Examples include digital platforms for energy trading and tools that simplify the operation of energy plant data – both of which are embedded in the DNA of these companies. These capabilities support the implementation of technologies that reduce operational costs and enhance business model efficiency.

The research corroborated the findings from Gebauer et al. (2020) and Nambisan et al. (2019), which highlight the critical role of technologies such as Digital Twins, IoT, Blockchain and AI in creating process automation and digital strategies for cleantech firms.

From the cases, we observed that digital capabilities enable agility and cost reduction, facilitating the trading of clean and renewable energy and leading to economies of scale. Digital competence was also found to encompass the capability to use technologies such as AI, IoT, Big Data management, blockchain, 5G and others that facilitate the implementation of solutions (Gupta et al., 2017; Ramadoss et al., 2018). In addition, digital capabilities enable a high level of customization for cleantech companies, allowing them to use digital platforms to align clients' demands with the technological solution. For example, creating an energy efficiency program to reduce energy expenditure and consumption in commercial companies, or providing specific credits and funding for the acquisition of renewable energy sources.

Digital capabilities emerge as a critical antecedent for cleantech firms to undertake scalability activities and minimize environmental impacts, thereby fostering more sustainable businesses, as it stems from the firm's roots and its business proposal for solutions (Monaghan et al., 2020). In this study, this category block represents the basis for a company to provide a product or service with the capacity to scale and attract consumers, while minimizing environmental impacts. Thus, the technology chosen to create a product or service must have aspects of environmental and social compensation that, in addition to minimizing the firm's internal costs, also reduce customers' expenses.

In sum, the evidence from the cases shows that digitalization (through AI, IoT, Big Data, etc.) enables better tracking of resource use, automates reverse logistics and develops tailored sustainability solutions (e.g. energy efficiency programs, customized funding for renewable energy adoption). Additionally, the cases highlight that born-digital cleantech firms, owing to their embedded digital capabilities (e.g. ability to integrate AI, IoT and data platforms), are better positioned to create CE-oriented strategies focused on minimizing resource use and environmental impacts while scaling operations. Digital capabilities provide the technological and organizational foundation needed to reconfigure business processes, enable resource-saving innovations and pursue environmental sustainability goals at scale. Thus, we propose the following:

P3. Digitalization enables firms to design and implement more effective CE strategies through data-driven tools and platforms that enhance traceability, predictive maintenance and CE strategies.

P4. Firms with stronger digital capabilities are more likely to develop and implement CE strategies.

Discussion

This study addresses the question: How do scaling activities foster the development of CE strategies in cleantech firms? By integrating research on scaling activities (Piaskowska et al., 2021; Nason & Wiklund, 2018) with emerging insights from CE literature (Noronha et al., 2022, 2023a; Nygaard, 2022; Suchek et al., 2021), we develop four propositions that explain how acquisition, financing, innovation and digitalization enable firms to develop and implement CE strategies and how digital capabilities are a key antecedent for scaling activities.

Although scaling activities have enhanced and accelerated the adoption of CE strategies, these efforts often reflect "low-hanging fruit" approaches, particularly narrowing, which emphasizes resource and material efficiency, rather than more transformative strategies such as slowing, closing, or regenerating (Bocken et al., 2025).

In this context, scaling plays a crucial role in enabling cleantech firms to acquire or partner with technologies that monitor pollution, greenhouse gas emissions and water waste. It also facilitates access to renewable energy sources through alternative financing mechanisms and promotes innovation and digitalization, aiming to improve efficiency – essentially, doing more with less.

Theoretical implications

First, our findings highlight that acquisition activities contribute to CE by facilitating access to technologies, resources and new capabilities that promote environmental sustainability management and operational efficiency. This extends prior research on the scalability of digital ventures (Piaskowska et al., 2021; Bohan et al., 2024) by explicitly linking acquisitions to CE outcomes such as waste minimization and material reuse.

Second, we show that financing and innovation activities play a dual role in supporting CE initiatives. Financing provides the necessary capital to scale up cleantech firms, which means scaling environmentally focused projects, such as renewable energy solutions and recycling initiatives. Innovation, in turn, drives the development of new products, services and processes that reduce environmental impact and extend resource lifecycles. This reinforces and expands upon findings by Noronha et al. (2023b); Fundação Getulio Vargas (FGV) (2019) on how cleantech firms leverage regulatory and technological opportunities for sustainable growth.

Third, our findings underscore digitalization as both a structural enabler and a dynamic driver of CE strategies during the scaling process. Digitalization also enables the blending of physical and digital environments through technologies such as IoT, AI, big data analytics, machine learning and smart sensors (Ramadoss et al., 2018). This creates operational flexibility, allowing firms to rapidly adjust, extend, or replicate processes – capabilities that are especially valuable during rapid scaling (Piaskowska et al., 2021). By investing in digital infrastructure – often cloud-based – firms can integrate services, manage distributed operations and analyze resource usage patterns without significantly increasing their environmental footprint (Nambisan et al., 2019). Digitalization enhances firms' capacity to track, manage and optimize resource flows across the value chain through real-time monitoring, predictive maintenance and reverse logistics automation – mechanisms that are critical for implementing CE at scale (Gebauer et al., 2020; Giustiziero et al., 2023).

Fourth, we identify digital capabilities as a key antecedent for embedding CE strategies into firms' scaling trajectories. Unlike digitalization, which refers to the deployment of digital tools and infrastructure, digital capabilities encompass a firm's accumulated knowledge, skills and routines that enable the effective use of digital technologies (Cahen et al., 2025; Cahen & Borini, 2020). These capabilities enable firms to reconfigure their operations, innovate resource-efficient solutions and respond promptly to shifting market and regulatory demands. Our findings address a gap in CE research by showing how digital capabilities shape both the design and implementation of CE initiatives (Suchek et al., 2021; Belitski et al., 2023).

Moreover, our study emphasizes that born-digital cleantech firms, due to their deep-rooted digital orientation, are particularly well-positioned to align scaling activities with CE objectives, reinforcing the link between digital competencies and sustainable business model innovation. Finally, our study demonstrates that scaling activities and digital capabilities are interlinked drivers of CE implementation, particularly for born-digital cleantech firms. These firms leverage digital technologies to grow and to embed environmental sustainability across their business models (Giustiziero et al., 2023; Russ, 2019).

This research demonstrates that clean technologies can serve as a foundation for organizations to develop CE strategies. The scaling process in cleantech firms is driven by technologies that require managing large volumes of data and developing increasingly autonomous systems. The propositions presented offer a roadmap for cleantech firms to assess their digitalization competencies, identify technological market pathways and generate positive externalities for the environment, economy and society.

Implications for practice

Our practical and societal contributions lie in demonstrating how companies can leverage digital capabilities to reduce environmental and social impacts. The solutions discussed – such as energy management, reduction of technological costs, water conservation and the promotion of responsible consumption – provide actionable approaches for firms seeking to implement CE strategies while scaling sustainably and managing natural resources in their daily operations.

Furthermore, the technologies and practices highlighted in our case studies (e.g. IoT, AI, big data) can inform governmental policies, regulatory frameworks and public sustainability targets. Policymakers can use these insights to design institutional environments that encourage companies to develop internal roadmaps and strategies aligned with environmental, social and governance principles. This supports climate action efforts connected to the UN Sustainable Development Goals, as emphasized in prior studies (Barbier & Burgess, 2017; Barbier, 2021).

Research limitations and future studies

Our study provides a basis for further investigation into the scalability of digital cleantech firms. The case-study approach was appropriate, and the sample size (12 cases) followed Eisenhardt's (1989) recommendations. However, some limitations should be acknowledged.

Given that all selected companies were based in Brazil, the results reflect a context-specific regulatory and technological environment that limits their broader geographic applicability. Additionally, to minimize sector-specific bias, we focused on infrastructure-related cleantech firms. Future qualitative research should include cleantech firms from other regions and institutional contexts. Research that extends beyond cleantech firms to enhance the generalizability of our findings should encompass a broader, more diverse set of cases, especially from various countries and industries. Additionally, lifecycle stage and maturity of cleantech firms constrain the assessment of CE strategies. These firms also provide a valuable context for testing and advancing CE strategies.

Finally, quantitative research involving larger samples of digital companies across various industries could empirically test the relationships proposed here, offering deeper insight into how scaling activities, CE strategies and digital capabilities interact.

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Associate editor: Luísa Margarida

Data availability

The entire dataset supporting the findings of this study is available upon request from the corresponding author.

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