



Do local subsidiaries have unique characteristics in strategies, knowledge, and digital transformation efforts to achieve circular economy goals?

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ABSTRACT

This study examines how circular business models (CBMs) and industry 4.0 technologies (I4.0Ts) can connect in the specific context of local subsidiaries. The study adopted a case study methodology, involving twelve semi-structured interviews with key board members of Schneider Electric. Multiple methods of data collection were used to derive robust findings, including interviews, reviews of company sustainability reports, and participation in a workshop organised by the company to learn about its operations. Interview data were analysed using thematic analysis. The results suggest that I4.0Ts may positively influence resource use reduction and circular economy (CE) goals. However, given the study's qualitative nature and single-company scope, these findings should be interpreted as indicative rather than broadly generalisable. The adoption of I4.0Ts appears driven mainly by legitimacy, stakeholder consensus needs, and regulatory compliance pressures. The study is based on a single case and primarily qualitative evidence; broader validation through comparative or quantitative research would strengthen the robustness of the insights. This research offers tentative insights for other companies considering CE-oriented digital transitions, highlighting potential benefits and challenges. Policymakers are encouraged to support firms in addressing knowledge transfer and workforce resistance barriers. This study adds to the debate on how local subsidiaries can contribute to the CE through I4.0Ts, while also stressing the need for a cautious interpretation of claims about universal advantages.

Introduction

In the business field, attention and sensitivity to sustainability in general and environmental aspects in particular have increased exponentially over the past years. In this context, the circular economy (CE) plays a key function, assuming, over time, an autonomous space both at the operational level and at the level of academia because of its significance and the specificity of the subject. The CE can boost enterprises' productivity and efficiency (McKinsey & Company, 2024; Pieroni et al., 2021). However, companies need significant investment in technology and competencies to be able to introduce efficient circular business models (CBMs; Modgil et al., 2021; Suchek et al., 2021). CBMs require a high level of digital knowledge and a complex process of implementation to realise the related technological innovations (Antikainen et al., 2018; Frank et al., 2019; Rosa et al., 2020; Yao et al., 2023).

High start-up costs can represent a barrier to the implementation of CBMs (Wuni, 2022). Scholars have highlighted how a CE approach is usually applied because of holding strategies and following group instructions (Jaeger & Upadhyay, 2020), allowing subsidiaries and

branches to implement consolidated models and reduce investment risks. Further, multinational enterprises (MNEs) are crucial in implementing a CE approach that can support a 'global' strategy for achieving sustainable development (Arenas & Ayuso, 2016). At the same time, it is important to comprehend the role of local entities in strategies orientated towards the CE and related information technology (IT) processes, or if they are an active part of decision-making processes, contributing and possibly being able to modify (and if so, to what extent) the directives set at the parent company level (Gallaud & Laperche, 2016; Geissdoerfer et al., 2023).

There is a gap in the literature on the existing relationship between CBMs and Industry 4.0 technologies (I4.0Ts); in particular, the role of intragroup strategy and the impact that parent company strategies can have on local subsidiaries have not been adequately investigated (Foss & Pedersen, 2002; Kruehler et al., 2012). Addressing these gaps, the current study aimed to answer the following research question: How can CBMs and I4.0Ts connect in the specific context of local subsidiaries?

To answer this question, we employed a single case study approach, focusing on Schneider Electric (SEI) – a company significant to our

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study purpose (Yin, 2004). SEII is a French subsidiary company that has been involved in sustainability and circular business policies for long. To better comprehend the above-mentioned relationship between I4.0Ts and CBMs, as well as related strategies and management approaches, we conducted 12 semi-structured interviews and codified the interview data, also analysing the data obtained based on the public information available (Blandford, 2013; Diefenbach, 2009; Blandford, 2013).

The findings demonstrate that even in the presence of resistance to change, local subsidiaries appear to apply I4.0Ts (e.g. big data analytics (BDA), cloud computing (CC), internet of things (IoTs), and artificial intelligence (AI)) under the parent companies' coordination, to implement CBMs, which has a positive influence on the CE paradigm.

The study has several academic, practical, and legislative implications. From an academic perspective, to our knowledge, the study is the first to link CBMs and I4.0Ts from the perspective of a subsidiary. Under a managerial orientation, it highlights how subsidiaries, even if small entities, can benefit from consolidated group investment, moving towards the CE more easily and introducing complex technologies. Lastly, for regulators, the findings suggest that the CE and I4.0Ts should be coordinated and support investments in this domain should be promoted by providing specific facilitations, such as promoting training courses.

Literature review

Theoretical framework

This study draws from two theoretical frameworks: stakeholder theory and institutional theory.

According to stakeholder theory (Freeman, 1984), a company's success depends on its capacity to satisfy all stakeholders' needs (Alatawi et al., 2023). A company constitutes several counterparts, in addition to its shareholders, which can both affect and be influenced by the company's operations and decisions in different ways. Therefore, the aim of a company should be to take account of the needs of all its stakeholders, rather than exclusively increasing the wealth of its shareholders, by adopting good management practices that encourage the creation of good relationships with all stakeholders. This is particularly relevant in the current era, characterised by increased attention towards sustainability issues by all stakeholders. Stakeholders' attention to sustainability matters encourages companies to consider them in their strategies (Huang & Kung, 2010).

According to institutional theory, companies are economic units whose actions are influenced by institutions in the setting within which they act (Campbell, 2007; Roe, 1991). Institutional theory is used to justify homogeneity among companies' actions (DiMaggio & Powell, 1983). The main idea is that companies that operate in countries presenting institutional similarities adopt homogeneous actions (La Porta et al., 1998).

DiMaggio and Powell (1983) introduced the term isomorphism to describe the process of homogenisation of companies, identifying three types: mimetic, normative, and coercive. Mimetic isomorphism derives from the choice to resemble other companies, whereby companies act in the same way as other companies. Normative isomorphism occurs when companies act in a way that is considered right according to the professionalisation of a field or in line with the values, beliefs, and cultures prevalent in a given society (Gallego-Álvarez & Pucheta-Martínez, 2020). Coercive isomorphism occurs when companies operate in a way to comply with laws and regulations.

Based on previous theoretical arguments, companies tend to adopt I4.0Ts and/or CBMs if they are subject to societal pressures and operate in countries characterised by greater stakeholder attention and/or the presence of regulations towards digitalisation and sustainability (Boura et al., 2020).

Both these theories have been widely used to explain the sustainability initiatives implemented by companies, as well as the decision to adopt I4.0Ts. Considering their similarities and interconnections, these

theories have often been considered complementary, adopting a multi-theoretical perspective. They are derived from political economy theory and are believed to be 'system-oriented theories' (Gray et al., 1996). Moreover, they are valuable to investigate the relationship between a company and the society in which it operates. In stakeholder theory, the focus is on the stakeholders present in society, considered at the individual level. In institutional theory, the focus is on the values, laws, and institutional practices prevalent in society. However, these values, laws, and institutional practices are indirectly affected by the company's stakeholders. Both theories investigate how stakeholders, or the wider society, influence a company's operations. Therefore, they have been widely considered as complementary – rather than competing – theories. With regard to MNEs, composed of numerous subsidiaries located in different countries, they pay attention to both different stakeholders' needs and country-specific characteristics in defining their strategies and activities (D'Souza et al., 2020; Shapiro et al., 2018), such as the implementation of I4.0Ts and/or CBMs, to ensure legitimacy in both home and host markets (Ajwani-Ramchandani & Bhattacharya, 2022). From this perspective, operating at a global scale, MNEs are morally obliged to implement strategies that can support sustainability and climate change goals (Yang et al., 2023). Scholars have pointed out that the adoption of a global policy on the CE would transform the economic function of resources by reducing vulnerability to resource price shocks and investment risks (Preston, 2012).

The CE in MNEs

CE is a system that, moving beyond the linear model, contributes to waste reduction and resource efficiency improvements through strategies that help reuse and recycle materials and products in production and consumption processes (Khan et al., 2021). The CE paradigm has been diffused since the 1970s and is articulated along seven dimensions – reduce, reuse, recycle, recover, rethink, repack, and refurbish – better known as the seven Rs (Bagnoli et al., 2021; Kirchherr et al., 2017).

To resolve the problems of waste generation and resource scarcity (MacArthur, 2013; Geissdoerfer et al., 2017; Rosa et al., 2020), the CE paradigm also encompasses approaches contributing to the achievement of Sustainable Development Goals (SDGs; Ghisellini et al., 2016; Rashid et al., 2013; Schroeder et al., 2019), particularly the environmental targets (Geissdoerfer et al., 2017; Kristensen & Mosgaard, 2020; Skare et al., 2023; Yin et al., 2025).

Companies have implemented CE principles by adopting different CBMs. Specifically, CBMs are defined as companies' ecosystems for generating, securing, and delivering value by extending the useful life of products through remanufacturing, repairing, or designing long-life or circular products (Bocken et al., 2016; Nußholz, 2017; Oghazi & Mosaghel, 2018). CBMs cover the entire product life cycle, from cradle to death, from the extraction of raw materials to the recycling phase of the components of discarded items (Bagnoli et al., 2021; Lewandowski, 2016), allowing the extension of the life cycle of goods with a view to recycle, reuse, and remanufacture (Urbiniati et al., 2017). In other words, CBMs allow the achievement of the seven Rs paradigm aimed at reducing, through different stages, the inputs (raw materials) and unwanted outputs (waste and emissions) of the system (Haupt et al., 2017). Thus, CBMs represent a different approach to managing business through which companies can create value by implementing CE principles (Bocken et al., 2016; Lardo et al., 2020; Lewandowski, 2016; Lüdeke-Freund et al., 2019; Planing, 2015; Urbiniati et al., 2017).

With global recognition of the CE paradigm, companies may declare that they have adopted CBMs to gain legitimacy and enhance their reputation, even if this may not be true, creating a misalignment between the information released and actions implemented – a phenomenon called greenwashing (Sauerwald & Su, 2019). The fact is that high start-up costs can represent a barrier to the implementation of CBMs (Wuni, 2022). This is particularly true in MNEs that, for many years, have been considered companies oriented towards 'unsustainability',

given their negative impacts on both society and the environment (Linnenluecke & Griffiths, 2013; Schaltegger & Burritt, 2018). MNE operations are influenced by diverse location-specific characteristics (Shapiro et al., 2018). Considering their dimensions and impact across different countries (Amba-Rao, 1993), for many years, stakeholders have pushed MNEs to adopt a sustainable approach (Schaltegger & Burritt, 2018; de Oliveira et al., 2023).

However, although sustainability has been recognised as an important objective that should be managed and achieved by MNEs (Ocelík et al., 2023; Orlitzky et al., 2003), there is no consensus on how MNEs could implement sustainability strategies in their activities. One of the aspects investigated in prior research concerns the relationship between the head office and subsidiaries located in different countries, characterised by their own culture and institutional setting; the literature suggests two different strategies that MNEs could adopt to implement sustainability strategies (Schaltegger and Burritt, 2018). The first one is a global sustainability strategy, according to which the head office defines a unified and centralised sustainability strategy that local subsidiaries have to adopt independently from analyses of their impact on different institutional settings. This approach would allow subsidiaries to implement consolidated models and reduce investment risks. Meanwhile, MNEs could also identify various local and decentralised sustainability strategies. Thus, the strategy adopted by each local subsidiary could better address the specific country's needs. However, this would mean the lack of a unified and global strategy implemented by the MNE overall. Other solutions to implement sustainability within MNEs are located within the two extreme positions mentioned above, defined as local, transnational, and regional strategies (Arenas & Ayuso, 2016; Bondy & Starkey, 2014; Brown & Knudsen, 2012) that attend to both local and global interests.

Scholars have called for more research on the approaches adopted by MNEs in implementing sustainability strategies at both the home level and in different local subsidiaries (Beddewela & Fairbrass, 2016; Kolk & Perego, 2010). This study specifically focused on the CE approach adopted by a local subsidiary. Specifically, the study focused on the determinants of CBMs, particularly investigating the role played by I4.0Ts in fostering CBMs in local subsidiaries, to understand both the diffusion of CBMs and the challenges faced by local subsidiaries in aligning with stakeholders' expectations and managing institutional pressures. Despite the research on MNEs' role in achieving sustainable development, there is scarce evidence on the implications of I4.0Ts for sustainability in MNEs (Ocelík et al., 2023). In fact, most previous studies have investigated the influence of I4.0Ts on MNEs' business operations (Luo & Zahra, 2023) or the relation between I4.0Ts and implementation of CE principles (Awan et al., 2022; Hallioui et al., 2022; Rejeb et al., 2022; Toth-Peter et al., 2023); however, few studies have analysed the role played by I4.0Ts in fostering CBMs in MNEs, although it is an important stream of research warranting further attention (Ocelík et al., 2023).

Role of I4.0Ts in enhancing CE practices

I4.0Ts refer to several technologies developed within Industry 4.0, all united by the intent to promote cost reductions and quality improvements and increase the level of flexibility and speed in production processes (Olsen & Tomlin, 2020; Strazzullo, 2024). Improving production processes at both intra- and inter-organisational levels, the objectives are to solve problems associated with bottlenecks in production systems and increase the levels of production efficiency.

Studies on I4.0Ts have identified different technologies within Industry 4.0, thus yielding inconsistent findings. Some technologies, such as CC, are reported in almost all prior studies; others, however, are examined in only a few studies. I4.0Ts mainly used in the manufacturing sector include adaptive robotics, simulation, embedded systems, IoT, cyber security, CC, virtualisation technologies, and AI (Chiarini, 2021; Indri et al., 2019).

In the last few years, scholars have investigated the effectiveness of I4.0Ts for environmental sustainability (Ferreira et al., 2023; Stock & Seliger, 2016) and the CE (Ajwani-Ramchandani et al., 2021; de Oliveira et al., 2023; Massaro et al., 2021). Among the first authors who investigated the usefulness of I4.0Ts from an environmental sustainability perspective were Stock and Seliger (2016). They conducted a review of the state of the art of I4.0Ts and pointed out that these technologies ensure better allocation of resources, such as water, energy, and raw materials. Different I4.0Ts permit companies to reduce, reuse, and recycle material and energy resources, to extend the use phase or intensify it, and even to replace products with services and software solutions (Agrawal et al., 2022; Kortelainen et al., 2019; Montes-Pineda & Garrido-Yserte, 2024). Thus, different scholars highlight that I4.0Ts have the potential to enhance a company's production processes with respect to environmental management (Lopes de Sousa Jabbour et al., 2018), also fostering the transition towards the CE (Ajwani-Ramchandani et al., 2021; Awan et al., 2022; Oyinola et al., 2022; Tseng et al., 2018; Yu et al., 2022). However, some scholars have expressed concerns, mainly with respect to the environmental costs associated with I4.0Ts (Ocelík et al., 2023). Even though they support both digitalisation processes and economic growth, I4.0Ts are energy-intensive, consuming substantial amounts of energy (Liang et al., 2022). For instance, the European Union (EU) requires regulators to introduce energy efficiency requirements to govern the impact of AI on environmental sustainability under Regulation (EU) 2024/1689 (better known as the EU AI Act). Another negative impact from the use of I4.0Ts is related to the increased amount of waste from the disposal of both the devices and hardware used (Chen et al., 2020; Chiarini et al., 2020; Oláh et al., 2020).

With regard to MNEs, de Oliveira et al. (2023) suggest that the use of I4.0Ts enables the diffusion of CE principles, by minimising waste, optimising resource use, and extending the lifespan of products.

The use of different I4.0Ts can foster CE implementation by modifying a company's strategies and business models. Technologies such as IoT, AI, BDA, and CC do more than automate processes – they enable new forms of value creation that align with CE goals (Ajwani-Ramchandani et al., 2021; Awan et al., 2022). For instance, IoT facilitates real-time resource monitoring and reuse, while BDA enhances asset traceability and predictive maintenance, contributing to reduced waste and improved efficiency. These technologies also serve as ways to increase legitimacy and consensus in highly institutionalised environments, supporting the view that technological adoption is not merely a technical decision but a strategic response to stakeholder and institutional expectations (Ocelík et al., 2023). Thus, I4.0Ts act as institutional enablers of CE, reinforcing the interconnectedness of environmental, technological, and social dynamics.

However, the effectiveness of I4.0Ts in the transition towards a CE approach depends on both the process type and the technology used (Mohamed et al., 2019; Ocelík et al., 2023). With respect to energy, for example, scholars (Said et al., 2020; Shrouf & Miragliotta, 2015) have noted that IoT has a positive effect on energy, reducing its utilisation. At the same time, other scholars have revealed positive effects on energy consumption deriving from the use of AI or simulation tools (i.e. Baccarelli et al., 2017; Bag et al., 2021). However, there are also scholars arguing that the use of I4.0Ts does not lead to a reduction in energy consumption (i.e. Kamble et al., 2018; Wan et al., 2016). Concerning waste, some scholars found that the use of CC and additive manufacturing allows the reuse of waste within the supply chain (Nascimento et al., 2019). Other scholars found that additive manufacturing helps decrease greenhouse gas emissions (i.e. Huang et al., 2016). In addition, studies focused on big data technology found that it helps reduce resource waste by monitoring the production process in real time (Bag et al., 2020; Bag et al., 2022; Lombardi et al., 2022; Yu et al., 2018).

Evidently, a consensus on the relationship between different I4.0Ts and the CE is lacking. Therefore, it is necessary to better understand

Table 1
Question items.

N°	Macro area	Interview topics	Sources
1	Circular Economy business models (CBMs)	Does the company plan processes to reduce energy consumption and raw material use?	Zhu et al., 2005; LaForge, 2006; Lee et al., 2007; French and Zeng et al., 2017; Bag et al., 2021
2		Does the company plan processes to improve the energy efficiency of production equipment?	
3		Are materials for product packaging used repeatedly?	
4		Does the company plan processes for the reuse of waste materials for the manufacture of other products?	
5		The company plans processes for waste recycling	
6		What are the differences between theory and practice observed by the company towards the green process?	
7		Does the company use I4.0Ts in its business processes?	
8		What are the policies adopted by the company to reduce waste production from a circular perspective by adopting technological tools?	
9		Does the company plan processes to improve the energy efficiency of production equipment?	
10		Are materials for product packaging used repeatedly?	
11	Big Data Analysis (BDA)	Does the company use analytical-statistical models to improve decision-making and performance with reference to the Circular Economy paradigm?	Srinivasan and Swink, 2018; Dubey et al., 2019 a; Dubey et al., 2019b; Benzidia et al., 2019; Carvalho et al., 2020; Bag et al., 2020; Ndou et al., 2021
12		Does the company use data visualisation techniques or devices (e.g. dashboards, computers, telephones) to help decision-makers understand complex information?	
13		Through the more efficient use of BDA, has the company extended the life cycle of the machine and reduced industrial waste? If yes, can you give some examples?	
14	Artificial intelligence (AI)	The company envisages the use of specific controllers and monitoring systems to enable the automation, monitoring and control of processes and objects in real time?	Wang et al., 2015; Yu et al., 2015; de Sousa Jabbour et al., 2018; Rajput and Singh, 2019; Alacer and Machado, 2019; Frank et al., 2019
15		With reference to the Circular Economy paradigm, does the company use autonomous	

Table 1 (continued)

N°	Macro area	Interview topics	Sources
16		and coordinated subsystems that are connected at all levels of the production process, thus providing adequate interaction between humans, machines and products?	
		Is the company committed to adopting programmes and tools for physical interaction between robots and humans in a collaborative working environment in order to achieve quality, precision and accuracy in the production process? Does this affect the achievement of company performance?	
17	Cloud computing (CC)	With reference to the Circular Economy paradigm, does the company support the full sharing, high utilisation and on-demand use of centrally distributed production resources?	Alacer and Machado, 2019
18	Internet of Things (IoT)	With reference to the Circular Economy paradigm, the company can monitor natural resources (soil, water, humidity, wind, temperature, etc.) thus providing on-line, i.e. shared, real-time information on the environment?	Kamlmykova et al., 2018; Rajput and Singh, 2019

whether and how different I4.0Ts influence the CE (Chiarini, 2021; Ocelík et al., 2023), particularly in subsidiaries that have not received much attention in previous studies compared with MNEs.

Method

Design

Case studies are widely applied in the social sciences to investigate the actions of diverse entities to address emerging issues, valuable to answer ‘how’ and ‘why’ questions when studying related phenomena (Yin, 2018). This study thus employed the case study method, optimal for analyses of complex phenomena (Chiarini, 2021; Eisenhardt, 1989; Geels, 2002; Gummesson, 2006). It was found to be particularly suited to answering the research question, as it allowed for an understanding of the experiences of and relationships between stakeholders that emerge within the specific context of the subsidiary company. As the analysed phenomenon is complex and specific, opting for a single case study allowed a deeper understanding of the effects of the company’s decisions, as well as a richer investigation of the connection between the actions undertaken and the related outcomes (Ahrens & Dent, 1998; Chiucchi & Montemari, 2016). According to Yin (2018), the case study method provides significant knowledge about the object of investigation in terms of its capacity to generate theoretical reflections and practical implications for the examined phenomenon (Abma & Stake, 2014; Stake, 2005).

As part of the current case study, first, several semi-structured interviews were conducted with key board members working within the SEII group (hereon referred to as the group; Dearnley, 2005). In the

Table 2
Source and use of data.

Source	Type of data	Use in the analysis
Interviews	Twelve interviews: Computer operator Materials planner and mechanical engineer Property and security facilities manager Environmental Health and Safety Manager Human Resources Manager General Manager Industrial Plant Production Engineer Team leader of the welding department Team leader of the BCC2 packaging department Team leader of the warehouse Structured operator of the MITOP and MINITOP departments Temporary worker of the MITOP and MINITOP departments	Cross-checking the truthfulness of statements made during the interview.
Official public documents	Sustainability Report 2022	Gathering data on the history and expectations of company- stakeholder relations, sustainability strategies adopted by the Group.
Workshop	Project Description AGILOX- AGV	Measuring the impact of the digital transition process on business performance

second step, from July to December 2024, we expanded the semi-structured interviews to include team leaders, structured workers, and temporary workers. This allowed us to gain insights into the perspectives of those who may not make theoretical decisions regarding the use of technology but are involved in its practical implementation. These interviews were structured into closed and open-ended questions to ensure the quality of the interview and to avoid bias in the responses from the interviewees (Chisnall, 1986). Semi-structured interviews have often been considered by scholars as an efficient research methodology in individual case study circumstances because they allow for an in-depth investigation of specific points that emerge during interviews. Using the open-ended question format (Table 1) presents several characteristic advantages: (a) it deals with one or more complex phenomena; (b) it promotes freedom of response to some degree; (c) it assumes a multiplicity of data to reinforce the observations; (d) it is based on qualitative data; (e) and it presents itself as a detailed window into the phenomenon in relation to the factors abstractly observed (Ogawa & Malen, 1991).

Meanwhile, several authors have suggested that using multiple methods of data collection supports data triangulation and strengthens the results (Creswell & Miller, 2000; Eisenhardt, 1989). Thus, the following data collection techniques were used in this study: a) conducting 12 semi-structured interviews; b) analysing, reading, and interpreting company sustainability reports; and c) attending a workshop organised by the company to learn about its AGILOX-Automated Guided Vehicles (AGV) project and the rationale underlying its operational activities. Table 2 presents the details of this information and how we used it in the current study. The interviews were oriented to (a) describe the CBMs implemented in the processes, (b) understand the influence of I4.0Ts on CE strategies, and (c) illustrate the related benefits and costs.

The following table presents the list of question items used in the interview and the related literature source.

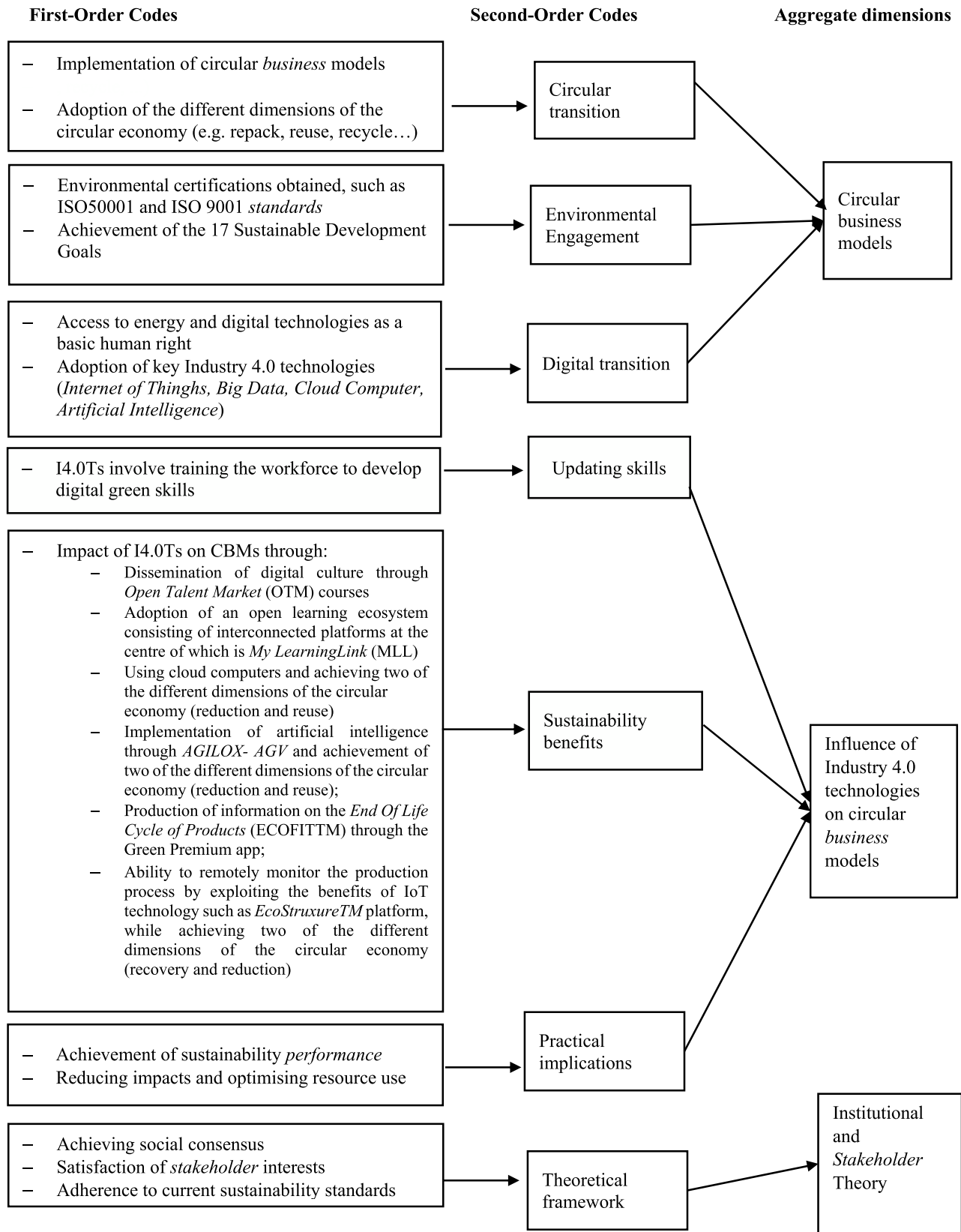
The case study approach followed in this research was carried out

initially through interviews. The first step involved conducting ‘standard interviews’. All the proposed questions had the same structure to avoid bias and build confidence in interviewees. The questions started from the main issues identified in the literature concerning CBM adoption. The interviews commenced in July 2023 and ended in December 2024. The choice to conduct 12 interviews was informed by Creswell and Miller (2000) and Morse (1994), who state that a well-balanced interview sample should include a minimum of five interviews; each interview lasted approximately 90 min. Interviewees were selected based on their involvement in the green process. Interviews continued until sufficient results were obtained to demonstrate data saturation, highlighting both the positive and negative aspects of I4.0Ts implementation.

Saturation was assessed using a ‘code frequency counts’ approach, based on which the interview transcripts were reviewed and interviews continued as long as new codes emerged, until the frequency of new codes decreased and no more codes were obtained (Hennink & Kaiser, 2022). The latest available version of NVivo 15 (August 2024) was used for data analysis (Richards, 1999).

The interviews were recorded and transcribed before being examined using thematic analysis, following the six-step method proposed by Braun and Clarke (2006): a) defining themes; b) adopting a bottom-up approach to theme identification; c) becoming familiar with the data; d) creating initial research codes; e) identifying, reviewing, and mapping themes; and f) drawing conclusions. Data anonymity was ensured following ethical codes. The interview questions were articulated to collect data on the participants’ opinions on the company’s operational decisions, in particular, the strategy and choices adopted concerning sustainability and CE issues; the sustainable business model implemented; the relations with stakeholders; the different I4.0Ts implemented, their benefits, and the possible harms generated by them; and the impact of I4.0Ts on the sustainable business model adopted and the achievement of sustainability goals, especially related to environmental outcomes. We chose a single-case embedded design (Yin, 2018), justified by the relevance of SEII as an impact-driven company committed to bridging the gap between progress and sustainability for all through their Schneider Sustainability Impact (SSI) transformation dashboard.

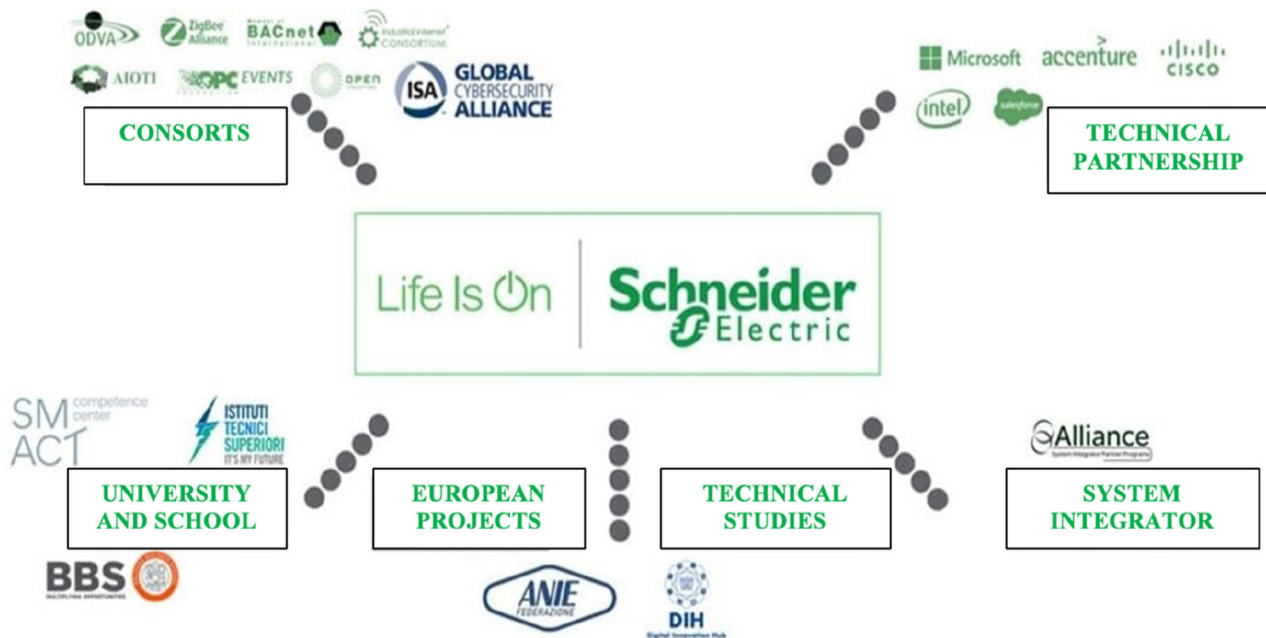
We adopted a single case study approach because our empirical research satisfies two crucial conditions reported in the research methods literature (Ozcan et al., 2017): (1) the case has not been previously accessible to researchers because of the lack of research projects about the impact of sustainability and technology programs within economic settings; and (2) the case has been observed longitudinally since we collected data from July 2023 to December 2024. The main concepts were identified following the methodology developed by Gioia et al. (2013), using multiple rounds of open coding, moving from in-vivo codes (e.g. simple descriptive phase) to second-order codes (e.g. thematic coding of circular transitions; Strauss & Corbin, 1990). First, we created analytical codes and categories; the interviewees’ narratives were listed to extrapolate key concepts while mitigating disruptions in interview flow, using Strauss and Corbin’s (1998) axial coding approach. Through the first-order coding, we considered the following themes specifically significant: implementation of CBMs, obtaining environmental certification by SEII, the adoption of I4.0Ts, achievement of 17 SDGs and sustainability performance, the effectiveness of I4.0Ts on the CBMs, obtaining social consensus, and adherence to current sustainability standards. Second-order themes and aggregate dimensions were generated in the second phase. The second phase is the most delicate as it allows the macro-level themes to be systematically ordered by the first-order codes using grouped categories and combining existing theory and empirical evidence. In particular, the first-order coding phase identified core concepts, for example, circular transition, environmental engagement, digital transition, updating skills, sustainability benefits, practical implications, and theoretical frameworks. To ensure a good data structure and proper interaction between first- and second-order codes (Gioia et al., 2013; Van Maanen, 1979), an



Coding scheme adapted from Gioia *et al.*, 2013.

Fig. 1. Coding scheme.

Coding scheme adapted from Gioia *et al.* (2013).



Reworking of sustainability report

Fig. 2. The Schneider Electric Group.
Reworking of sustainability report

inferential path of data analysis was followed from an inductive method (development of first-order themes) to an abductive one (development of second-order themes, aggregate dimensions, and reference theory). The last step involved the formation of three general concepts by combining the second-order categories informed by theories and first-order codes: (a) CBMs; (b) influence of I4.0Ts; and (c) institutional and stakeholder theories. Triangulation with other sources and comparison with the interview data enabled the refinement and reinforcement of interpretations (Yin, 2004). Interviews represent the key element of this investigation; however, the macro-level themes that emerged were triangulated with other public data sources, such as information extracted from the company's website, annual sustainability reports, and the AGILOX-AGV Project Description, where AGILOX-AGV represents the introduction of intelligent and scalable autonomous mobile robots capable of optimising intralogistics flows without fixed infrastructure thanks to decentralised X-SWARM technology and a "plug & perform" approach.

Through triangulation, it is possible to examine a research phenomenon from multiple perspectives and address potential construct validity issues, as multiple sources of evidence essentially provide multiple measures of the same phenomenon (Yin, 2018). Indeed, other sources, such as official public documents from SEII (e.g. the 2022 Sustainability Report), supported the data obtained from the interviews. It was thus possible to collect data on the history and expectations of the company-stakeholder relations and the sustainability strategies adopted by the Group. Furthermore, thanks to the participation in a workshop held at the Casavatore (city) site on 24 September 2023, it was possible to estimate the impact of the digitisation process on company performance through the reading of the Project Description AGILOX-AGV.

Furthermore, triangulation made it possible to involve various actors; the following members of the company under investigation were interviewed: Computer operator, materials planner and mechanical engineer, property and security facilities manager, environmental health and safety manager, human resources manager, general manager, and industrial plant production engineer. The data structure derived from this analysis is presented in Fig. 1.

Setting

SEII is a French subsidiary company that has been carrying out sustainability work for approximately 15 years and has adopted circular business, energy efficiency, and waste reduction policies, even before sustainability became a *modus operandi*.

The company has a worldwide presence. It is a Fortune Global 500 company, is listed on the Euronext Exchange, and is a component of the Euro Stoxx 50 stock market index. SEII was founded during the first Industrial Revolution in 1836 after taking over the 'Le Creusot' mine and smelter in France. CE deployment in the Schneider group is driven by the head office (France). In 1891, SEII became a leading armaments company and entered the emerging electricity market.

The first extension into Germany and Eastern Europe took place in 1919, thanks to the European Industrial and Financial Union (EIFU). However, it was not until 1999 that the company moved away from steelmaking and shipbuilding to focus its attention on the electricity sector.

In particular, from 2000 to the present, SEII has been dealing with uninterruptible power supply (UPS) systems, motion control, and automation. In 2022, the company had 135.000 employees and a production value of 34 billion euros. SEII provides digital energy and automation solutions to increase efficiency and sustainability by combining the world's leading energy technologies, real-time automation, software, and services into integrated solutions for houses, buildings, data centres, infrastructure, and industries.

SEII's basic policy is founded on the belief that access to energy and digital technologies is a basic human right, to be secured for future generations from a green perspective. The SEII philosophy is 'Life is On' – to enable everyone, anytime, anywhere, to make the most of their energy resources while respecting the environment and society.

The partnership of the group is illustrated in Fig. 2.

SEII gives more attention to CE issues. It also received various certifications attesting to its attention to environmental matters, such as the ISO14001 and ISO 9001 standards. ISO 14001 certification enables SEII to establish and sustain sound environmental governance at its sites, supporting continuous improvement to achieve environmental

Table 3
Achieving circular economy dimensions through I4.0Ts.

I4.0Ts	Technology name	Impact of I4.0Ts on business processes	CE dimension	Main benefit
<i>EcoStruxure platform</i>	IoT	Monitoring and control of CO2 emissions through the removal of the old methane-fueled equipment and then all the ventilation system will be powered by electricity	Recover; Reduce	Resource optimization, real-time monitoring
Cloud Computing	CC	Benchmarking between the different branches of the group, which meet weekly in digital format, while fostering collaboration.	Reduce; Reuse	Waste reduction, traceability, operational efficiency
EcoStruxureTM for Data Centres	BDA	Monitoring of climate change, the implementation of responses and the accurate analysis of results while acting on time	Reduce; Reuse	Resource and data sharing, energy efficiency
<i>Packaging Technology</i>	AI-BDA	Development of design and production methods that facilitate the disassembly, recovery and especially the recycling of products	Repack; Rethinking	Digitized training, material reduction
<i>OTM</i>	AI	Reducing the use of paper material thanks to the digital platform, and at the same time reducing the use of cars to almost zero, allowing users to take refresher courses from home	Reduce	Digitized training, material reduction
<i>AGILOX-AGV</i>	AI	Reduction of waste through accurate calculation of parts to be used and reuse of old parts that have been in storage for some time	Reuse; Reduce	Waste reduction, production optimization
EcoFit™	IoT	Revitalisation service for MPRS modular UPSs to extend the life of company equipment in a circular perspective	Refurbish; Recycle	Plastic reduction, recyclable packaging

performance. The ISO 14001 environmental management standard was published in 1996, and from the very beginning, SEII decided to certify its sites. The group certifies all industrial and logistics sites with more than 50 employees within two years of their acquisition or creation and all large tertiary sites with more than 500 employees. By the end of 2021, approximately 244 sites were registered with ISO 14001 certification, representing approximately 76% of the group's perimeter in terms of site area; 82% in terms of energy consumption; and more than 85% in terms of water consumption, waste generation, and volatile organic compound (VOC) emissions. Thus, the group has been able to meet stakeholders' expectations and address concerns regarding environmental sustainability and gain their consent, according to stakeholder theory (Freeman, 1984) and legitimacy theory (Suchman, 1995).

Findings

The interviews revealed that sustainability has been at the heart of SEII's transformation journey for more than 15 years. Indeed, the group is now a world-leading sustainability company and a key driver for all stakeholders in its ecosystem to accelerate its transition towards energy efficiency and sustainability.

With a network of over 52,000 suppliers worldwide, SEII is committed to developing lasting relationships with each of them while helping them introduce more sustainable practices to achieve SDGs. SEII has adopted CBMs; in fact, since 2020, the group, particularly the Bourguebus site in France, has been supporting the strategy to contribute to and accelerate the transformation towards CE. Bourguebus contributes to the implementation of four key aspects of SEII's CE strategy, shared by the group in its different subsidiaries: (a) the repackaging of new Schneider products whose packaging has been damaged; (b) the reuse and redistribution of Schneider products that are unused and unsold, and/or are returned by customers with the 'circular certified' label; (c) the restructuring of supply chain management to collect used Schneider products and send them to SEII Privas' partner site in France for repair and customer order management on the second-hand web platform; and (d) the dismantling of products for recovery and recycling of valuable materials. SEII gives more attention to the CE issue and uses I4.0Ts as a key to support sustainability.

In the sustainability report (2021), the chief executive officer (CEO) declared:

'Two technologies underpin the global economy's transition to a sustainable, more resilient and low-carbon future: digitization and electrification'.

The results reveal how the company, by implementing CBMs and I4.0Ts, is able to achieve some of the different dimensions of the CE paradigm (Table 3).

The group's decision to adopt I4.0Ts to implement CE strategies and, in particular, CBMs, is linked to the absence of standardised measurements to monitor the growing environmental concerns linked to digital technologies and its active engagement in bridging this gap. MNEs play a central role by possessing the technical and industrial knowledge that can help policymakers develop effective standards and measurements (Ocelik et al., 2023). Indeed, SEII, by promoting the automation of management processes to enable savings on energy emissions, is part of the European Green Digital Coalition. Through this coalition, SEII invests in the adoption of green technologies and participates in the creation of guidelines to ensure CE-consistent digitisation according to stakeholder needs (Ajwani-Ramchandani & Bhattacharya, 2022; D'Souza et al., 2020; Shapiro et al., 2018).

Table 3 reveals that one of the technologies employed by the company is enhanced reality – a system that, through a QR code, makes it possible to determine, for example, whether an electrical panel needs maintenance, even on lines and in buildings.

A noteworthy example is the EcoStruxureTM platform, which represents an enabler of IoTs (Agarwal and Brem, 2015); it allows the monitoring and control of CO2 emissions through the removal of old methane-fuelled equipment, with all ventilation systems subsequently powered by electricity. The group has decided to invest 1 million euros in this project to replace thermoelectric power plants with heat pumps in support of the adopted CBMs. These findings are in line with Shrouf and Miragliotta's (2015) results, who, through a literature review, traced the benefits of using IoT technology to reduce resource use and meet stakeholder expectations (Freeman et al., 1984). Furthermore, their analysis showed that the adoption of IoT allows a company to improve its environmental reputation and obtain sustainability certifications. Indeed, our respondents found that through the use of IoT, SEII obtained the ISO 50001 certification, increasing their prestige in the market.

Using EcoStruxureTM, the company achieves high performance outcomes and the two CE dimensions of 'recover' and 'reduce'. This is reflected in SEII's proposal to adopt EcoStruxureTM for Data Centres – an open, interoperable, IoT-enabled architecture and system platform:

It offers users a single pane of glass for efficient monitoring and operation of building systems to enable improved building efficiency, resource utilization, uptime, and occupant comfort through integration of electrical, lighting, security, fire, power, and other subsystems. By monitoring, controlling, organizing, and acting on heterogeneous data from building resources to a single system through advanced connectivity and integration with heterogeneous building systems, this technology tool provides better visibility and decision making, optimizes how and when energy is used, and enables proactive energy reduction.

This involves the use of CC by the group, enabling full sharing, high

utilisation, and on-demand use of centrally distributed production resources, from a CE perspective. Through CC, SEII manages to ensure the reduction of resources and reuse of existing ones. Alcácer and Cruz-Machado (2019) conducted a literature review on technologies for manufacturing systems and found that especially in large companies, CC technology is widely used as it contributes to cost reduction and the reuse of already shared networked material through the rationalisation of resources by dynamically scalable users who consume only the computing resources actually used (Branco et al., 2017). An example of CC use by SEII is benchmarking between the different subsidiaries of the group, with weekly meetings held online, also fostering collaboration. This approach is not limited to ‘top-down’ activities but seeks to involve everyone from a ‘bottom-up’ perspective – a way of making everyone an active part of sustainable change.

The implementation of EcoStruxure™ for Data Centres facilitates the adoption of BDA that enables climate change monitoring, response implementation, and accurate analyses of results while acting on time and ensuring the achievement of resource reuse and reduction. This is reflected in Bag et al.’s (2022) findings, who conducted an analysis on the role of BDA and dynamic capabilities (SC visibility) in developing the resilience of South African mining industries. Their study shows that through the implementation of BDA, it is possible to achieve both resource and community resilience that are, in turn, vital for the CE and the achievement of SDGs. The results show that BDA and IoT technology address the information needs of stakeholders (Awan et al., 2021) by also facilitating communication between the different actors involved in the supply chain (Massaro et al., 2021).

One of the central and common themes among all the interviews was the packaging technology used during the packaging process. SEII complies with regulatory dictates, for example, the Waste Electrical and Electronic Equipment Directive (WEEE) 2012/19/EU, also known as WEEE; it thus encourages the development of design and production methods that facilitate the disassembly, recovery, and recycling of products, preventing and reducing the amount of waste equipment going to landfills. On the one hand, a cross-functional team reviews packaging designs and explores and authorises the use of alternative packaging materials; on the other hand, various procurement teams engage with suppliers in all regions to ensure the implementation of the roadmap by suppliers to meet prescribed requirements.

To ensure streamlining of actions, specific categories of packaging materials have been identified for inclusion in processing. Through the concerted efforts of diverse teams, 21% of packaging spending has been attributed to sustainable packaging. Accordingly, the company has achieved two of the seven CE dimensions, repacking and rethinking; further, it meets the expectations of stakeholders not wanting the SEII group to be embroiled in environmental, social, and governance controversies or cases of greenwashing (Dorfleitner et al., 2020; Yang et al., 2020). In fact, Ajwani-Ramchandani et al. (2021) believe that taking into account stakeholder theory and the CE approach, together with some features offered by emerging technologies, can decrease waste generation at the packaging stage while exploiting the efficiency of packaging waste recycling. They also believe that some emerging technologies, such as mobile applications, geographic information systems (GIS), AI, and blockchain, act as catalysts to enable the implementation of a stakeholder incentive approach towards strong CE.

Table 4
Benefits generated by AGV technology.

	Max capacity	calculation	Average capacity	calculation	
Flow Selected	Max Pallet/h	Nb AGV/ max	Average Pallet/h	Nb AFV/ average	Saving (hrs/day)
Finish goods	13,00	0,69	10,00	0,53	4,7
Components	6,74	1,09	1,71	0,28	2,01
Total	19,7	1,8	11,7	0,8	6,7

However, the group suffers much from the regulatory pressure on packaging technology; it has thus been striving for years to develop a circular framework by adopting a systemic perspective in packaging design management. SEII makes extensive use of AI given its advantages; using the Open Talent Market (OTM) platform in 2020, it has enabled the matching of internal talent supply and demand with a transparent, digital, and borderless approach, enabling employees to drive their careers by discovering mentoring opportunities, new positions, part-time projects, and potential career paths. This technology, operating through a digital platform, helps reduce the use of paper material, and at the same time, reduces car use to almost zero, allowing users to follow refresher courses from their homes. OTM’s career planning feature was launched in June 2021, which nearly 20,000 employees accessed before the end of the year. SEII also has an open learning ecosystem consisting of interconnected platforms, at the centre of which is My LearningLink (MLL). This platform integrates e-learning, webinars, social learning, classroom learning, assessments, and comprehensive certification paths. The group continues to see increased use of the resources and increased digital learning, with more than 147,000 employees with access to the system; more than 74,000 employees visiting MLL each month; and over 24,000 learning content modules available in more than one language.

Digital learning consumption is at 73% for all employees and 79% for connected employees, up 45% from 2019 and stable from 2020. MLL was made available to all employees on mobile devices in 2021 (in addition to desktops) and is now also integrated with MS Teams to enable learning in the workflow. The partner portal MySchneider is deployed in 140 countries and offers a personalised learning experience with targeted training content that is most relevant to different people in the partners’ businesses. The training portal is accessible to more than one million SEII partners, distributors, resellers, and customers who have completed nearly 1.4 million courses since its inception in 2015. Several scholars (Leonhard et al., 2019) believe that in companies, especially large ones, the manager in charge of digital transformation assumes centrality, who is called upon to take charge of expanding the organisation’s internal mindset through training courses exploiting AI. Therefore, managing directors and CEOs must also have a clear overview under the dual technological and strategic-cultural lens. Miragliotta et al. (2018) emphasise the importance of the mastering phase that enables the transition to I4.0Ts, as it allows to seize opportunities related to the implementation of these technologies by monitoring data and preparing training courses for staff.

While attending the workshop held on 24 September 2023 described previously, a new AI technology in use at the Casavatore site, known as AGILOX- AGV, was presented. During the event, we posed some questions to the industrial plant production engineer and computer operator to understand the benefits of CBMs arising from the implementation of this technology. The interviews revealed that AGILOX- AGV helps reduce waste by providing an accurate calculation of the parts to be used and how to reuse old parts that have been in storage for some time, positively impacting two of the seven Rs, specifically, reuse and reduce (Fig. 2).

Thus, using AGILOX-AGV technology, it is possible to obtain an accurate calculation of the quantity of pieces of a given component to build a finished product (in this case, four pieces per finished product). Furthermore, AGILOX-AGV can calculate the number of pieces contained in the package to be handled (32 pieces) and the maximum capacity of the line, understood as the capacity of pieces that can be produced in 1 h. The ability to calculate the product autonomy of each pack is notable. If each pack contains 32 pieces and consumption is of 28 pieces, autonomy is calculated as:

$$A = \frac{\text{Number of pieces}(32)}{\text{Consumption}(28)} = 1.14h$$

For each code, SEII has indicated the pickup and deposit locations, with the corresponding aisle heights and widths. For example, finished goods are picked up from location A at a height of 700 mm and deposited

at location 11 on the floor (height 0).

For each code, the distance between the point of withdrawal and the point of deposit, and the distance between the point of deposit and the return to base is presented in column E. By taking advantage of the accuracy of the calculation about the quantities of parts to be used, the company also optimises production time. Indeed, it is estimated that approximately 6.7 h of work are recovered daily (Table 4).

Durrant-Whyte (1996) notes that AGV technology is implemented by many Italian companies to reduce waste, as it provides an accurate calculation of the parts to be used and an estimate of the old parts that have been in storage for a long time to be reused, positively impacting mainly two dimensions of the CE paradigm.

To bridge the gap between progress and sustainability, and respond to the pressing needs for cost reduction, business continuity, and increased performance with a rapid return on investment, SEII puts its expertise at the service of innovation in all key systems (from energy to industrial automation to building systems) at every stage, from design to end-of-life. An example is the implementation of the EcoFit™ technology that can yield end-of-life product information managed through the Green Premium app, encouraging efforts towards CE:

‘All changes in sustainability can be implemented if we lead by example through the adoption of systems to extend the life cycle of products’.

The advantage of this technology lies in the ability to revitalise MPRS modular UPSs by extending the life of the equipment and upgrading it with state-of-the-art technology. In 2021, a web configurator was developed to exploit the environmental benefits of the EcoFit™ service to recycle and refurbish medium voltage, low voltage, and reconditioned transformers from a CE perspective.

Several scholars argue that the implementation of I4.0Ts in processes could lead to high costs for companies (Dini & Dalle Mura, 2015; Franciosi et al., 2020). However, our interview data reveal that sustainability is not a cost for SEII, nor is safety. The interviewees stated that there are aspects that are not directly related to business, which do not produce an immediate profit, but build a culture in the society in which people operate through security and sustainability. Thus, the cost that is incurred in the immediate term is abundantly repaid later, following an inverse cost/benefit logic in which the latter outweighs the former. SEII has high performance outcomes. Thus, for this group, the implementation of I4.0Ts is not a negative point. In fact, one of the mottos of SEII is, ‘Before you understand what you consume, you must measure it through digital tools’.

The implementation of different technologies is a sustainability factor and a driver of CE principles adopted by the company. However, several negative aspects were mentioned during the interviews, such as the difficulty of transferring knowledge to the workforce in different subsidiaries (Chiarini, 2021). This is fully reflected in the work of Foss and Pedersen (2002), according to which if knowledge is highly linked to a specific context (e.g. to a certain market or local situation), it will be more difficult for another part of the company, in a different context, to understand and use it. In other words, the more specialised and adapted the knowledge is to a particular context, the less easy it is to transfer or apply it in other parts of the company.

Another important factor that emerged was workforce inertia:

‘During our 30 years of experience with the SEII group, we have noticed that there is often an aversion on the part of technical and operational staff to change, representing a problem for the company as staff, especially those with more years of work experience, are not adequately trained in technological change’.

Karadayi-Usta (2019) conducted a study at the Bosch company, and found that resistance to change is often caused by the lack of an educational system to prepare for innovation that mere upgrades to platforms cannot guarantee. This could also have a negative financial impact as the company invests resources to adopt I4.0Ts, but at the same

time, the staff are unaccustomed to change or inadequately trained, which can lead to cost overruns (Sovacool et al., 2014).

Discussion

This study adds to the growing body of research exploring the intersection between the CE and digital transformation, particularly within local subsidiaries. Our findings align with previous literature, reinforcing the significant role of I4.0Ts in enabling and accelerating the adoption of CBMs. The case of SEII highlights how technologies such as BDA, CC, IoT, and AI can serve as key enablers of CE practices by optimising resource management, reducing waste, and improving energy efficiency.

The implementation of EcoStruxure™ at SEII exemplifies how IoT-enabled systems can be leveraged to monitor and manage resource consumption in real time. This approach not only enhances operational efficiency but also supports key dimensions of CE, such as reducing waste and recovering materials. Similarly, the deployment of AGILOX-AGV technology at the Casavatore site shows how AI-driven automation can facilitate the reuse and optimisation of materials, contributing to both operational performance and environmental sustainability.

Our research contributes to the existing literature on the CE and digital transformation by focusing on the underexplored context of local subsidiaries. While previous studies (e.g. Chiarini, 2021) have examined the impact of I4.0Ts on environmental sustainability in broader contexts, our study delves into how these technologies are applied and adapted within the subsidiary of a multinational corporation. Chiarini (2021) emphasised the potential of I4.0Ts to improve environmental performance by enhancing resource efficiency, though he also highlighted that the effectiveness of these technologies varies depending on their application and the specific industrial processes involved. Consistent with this perspective, our findings illustrate how local subsidiaries can successfully implement these technologies to achieve CE goals, even when operating within the broader strategic framework set by the parent company.

Moreover, this study reveals that institutional and stakeholder pressures, as outlined in stakeholder theory (Freeman, 1984) and institutional theory (DiMaggio & Powell, 1983), play a critical role in shaping the adoption of I4.0Ts in local subsidiaries. SEII’s decision to invest heavily in digital technologies was largely driven by the need to align with stakeholder expectations and regulatory requirements. This finding aligns with Chiarini’s (2021) observation that companies often adopt I4.0Ts to maintain legitimacy and meet external sustainability pressures.

However, as noted by Chiarini (2021), the benefits of I4.0Ts are not universally guaranteed. The effectiveness of these technologies in promoting sustainability depends on how they are implemented and integrated into the company’s operational processes. Our study supports this conclusion by showing that, while technologies such as AI and IoT have delivered substantial benefits in reducing energy consumption and waste at SEII, their success is closely tied to the specific context of their use and the subsidiary’s ability to adapt them to local conditions. Despite all the widely discussed positive aspects, negative factors related to the implementation of I4.0Ts within the SEII group also emerged from the interviews.

Although most interviewees framed sustainability-related investments as strategic and performance-enhancing, our analysis also revealed several underexplored challenges associated with I4.0T adoption. Specifically, issues such as employee resistance to change, knowledge transfer barriers across subsidiaries, and insufficient digital training platforms emerged as recurrent concerns. Although qualitatively reported, these aspects are often minimised within managerial narratives and underrepresented in the broader literature, which tends to focus on the enabling potential of I4.0Ts. This reflects a gap that requires further empirical scrutiny.

As Sovacool et al. (2014) and Karadayi-Usta (2019) suggest, a lack of

structured educational infrastructure and cultural inertia can translate into inefficiencies, implementation delays, and cost overruns – downsides that are rarely addressed systematically in CE-related I4.0 research.

The difficulty of transferring knowledge to the workforce in different branches represents a significant challenge. As highlighted by the work of Foss et al. (2002), when knowledge is strongly linked to a specific context, such as a certain market or local reality, it becomes more complex for other parts of the company, operating in different contexts, to understand and apply it. In other words, the greater the specialisation and adaptation of knowledge to a specific environment, the more difficult it will be to transfer and utilise it elsewhere. A further obstacle that emerged is the inertia of the workforce, which is often reluctant to change (Hannan & Freeman, 1984).

Interviews revealed that technical and operational staff, particularly those with more years of experience, show an aversion to innovation, being ill-prepared to deal with technological change. Resistance to change is often due to the lack of an adequate education system to prepare staff for innovation, which simple refresher courses cannot guarantee (Karadayi-Usta, 2019). This difficulty in adapting not only slows down the technological transformation process but can also have a negative financial impact. Companies invest resources in the adoption of I4.0Ts, but they risk additional costs and operational inefficiencies due to staff who are unaccustomed to change or insufficiently trained. SEII could take some measures to overcome these problems. To address knowledge transfer challenges, SEII could incorporate locally sourced knowledge into the organisation through collaborative applied research projects with local universities or research institutes. This could help promote strong collaboration between industry and academia (Santos et al., 2009). The lack of an educational system, worsening inertia in the workforce, represents a barrier that can be resolved by efforts of a management team that can foster successful educational innovation (Sánchez et al., 2023).

In summary, this study advances the understanding of how digital transformation and the CE can intersect within local subsidiaries of MNEs. By investigating SEII's experience, we provide new insights into how I4.0Ts can be effectively leveraged to drive circular business practices at the subsidiary level, thus filling a gap in the current literature on the CE and digital transformation in multinational corporate contexts. Future research could build on this work by conducting comparative studies across different industries and subsidiaries to further elucidate the nuanced impacts of I4.0Ts on CE strategies in diverse organisational settings.

Conclusions

General remarks

This study explored the potential of I4.0Ts to support the CE within the specific context of a local subsidiary of a multinational enterprise. The findings indicate that certain technologies such as IoT, AI, and AGV may contribute to resource optimisation and waste reduction, aligning with CE principles. However, these conclusions should be read with caution due to the study's qualitative approach, the limited sample size, and its focus on a single firm and sector (Eisenhardt & Graebner, 2007; Yin, 2018).

While the evidence shows encouraging links between I4.0Ts and CBMs, it does not imply that similar benefits would automatically arise in different organisational or national contexts. Challenges such as knowledge transfer barriers and workforce inertia emerged clearly and suggest that the implementation of I4.0Ts does not guarantee success without complementary investments in training and cultural adaptation (Foss & Pedersen, 2002; Sovacool et al., 2014).

Policymakers and practitioners should therefore adopt a balanced perspective: viewing I4.0Ts as possible enablers of the CE but acknowledging the need for context-specific strategies and supportive

conditions to realise their full potential. Future research should test these preliminary insights across sectors and subsidiaries, ideally combining qualitative depth with quantitative measures to strengthen generalisability and practical relevance.

Implications

Theoretical implications

This study contributes to the ongoing debate on the impact of the CE on the economy and sustainable development. The results show the beneficial impact that I4.0Ts generate on CE strategies implemented by the sample company. The findings of the study have several implications. First, the results indicate that I4.0Ts have a significant influence on CE. Specifically, our study revealed the link between the different I4.0Ts adopted by the sample company and CE, suggesting how the various I4.0Ts implemented could be used to improve the seven Rs. This process can be adequately managed in the context of MNEs, where, apart from resistance to change, the result can have positive effects from an economic and sustainability perspective.

Practical implications

Seeing I4.0Ts as accelerators of CE, this study proposes that policy-makers promote the emergence of structures that can encourage both private and public organisations to use these technologies in business processes. Further, the specific relationship between the parent company and the local subsidiary highlights additional considerations regarding how to implement a business model created in the parent company context. Adopting this model requires an understanding of the overall system and a specific training process to realise the benefits of this change and appreciate the related advantages. An unmotivated request could produce a legitimate aversion to change, understood as an order without a logical positive trade-off between benefits and costs.

Although the results are from a single case study, they are generalisable to other firms with similar business and industrial characteristics. In particular, the impact of I4.0Ts on the implementation of CBMs is likely to be positive for subsidiaries of MNCs operating in highly resource-consuming manufacturing industries with high regulatory pressures.

The study provides input to regulators by showing the actions implemented by the company to introduce the CE paradigm into production processes, providing feedback on the CE Action Plan published in 2015. In addition, this research indicates the degree of adoption of I4.0T and the company's views on the ability of I4.0Ts to influence CE, informing policymakers of the emergence of structures that can encourage the use of these technologies in business processes. Additionally, it stresses the need to provide benefits for promoting training courses, especially in the context of private companies.

This paper discusses the influence of I4.0Ts on CE, specifically highlighting what benefits are associated with using I4.0Ts implemented by the company. In addition, it highlights certain negative aspects related to the adoption of I4.0Ts, such as the difficulty of knowledge transfer and inertia of the workforce. These insights on the negative aspects that emerged from the interviews help us compare the perspectives of those who theorise I4.0Ts in the CE context and those who use them in practice.

Recognising the contributing role of I4.0Ts in the green transition process, policymakers could envisage structures that can explain what benefits a company can gain from the use of key I4.0Ts such as IoTs, BDA, CC, and AI.

Future research directions and limitations

This research has some limitations, presenting avenues for further study. First, the analysis focused on a single case study. While the use of a single case study provides in-depth and rich data, the generalisation of our results to other companies might be limited. The findings could have been influenced by the specific process adopted by the company to

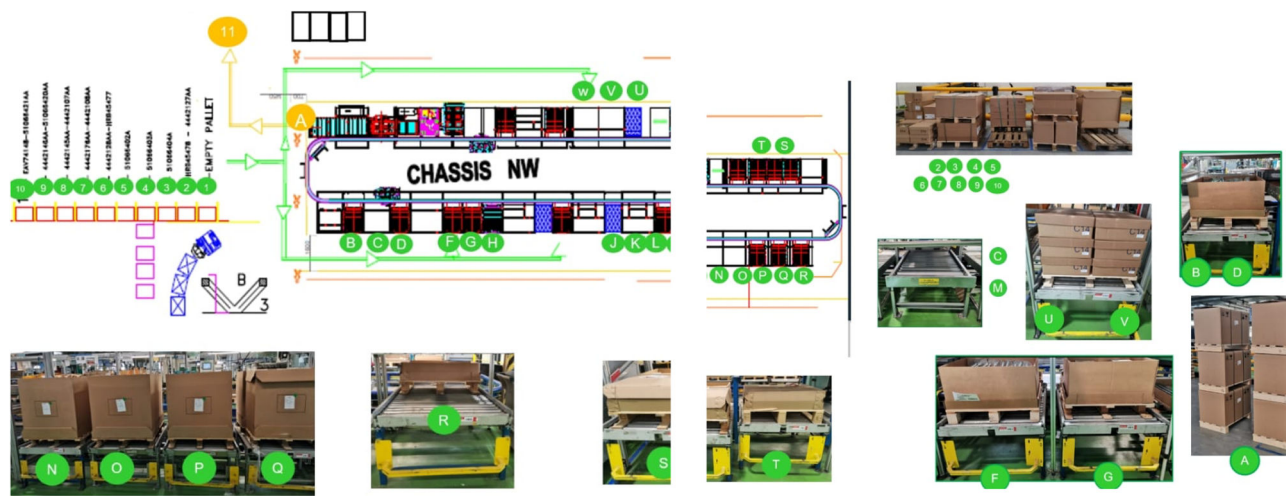


Fig. 3-. AGILOX.
Source from internal company documents

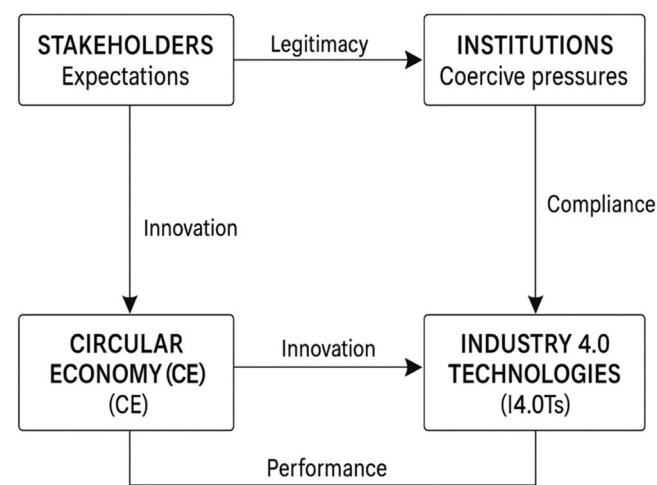


Fig. 4. Relationships between stakeholders, institutional Pressures, I4.0 Technologies and the Circular Economy.
Source: Authors' own elaboration.

develop the project. The inclusion of a comparative case, from another branch or subsidiary of the enterprise or from another company operating in the same industry segment, could have strengthened the study's overall findings. The near absence of negative comments during the interviews leads us to surmise that it would be appropriate in a future study to use other methodologies that would support the interview data to better clarify the negative impacts related to I4.0Ts on CE. Indeed, the study provides limited insight into the potential financial and organisational disadvantages associated with such technology adoption. This limitation highlights the importance of triangulating interviews with more quantitative or documentary evidence, such as internal cost reports or return on investment data, to fully understand the trade-offs involved in implementing I4.0T to support the CE (Bag et al., 2020; Chiarini, 2021; Sovacool et al., 2014). Recent accounting literature has pointed out that financial risks and cost inefficiencies may emerge during digital transitions if companies do not appropriately assess the long-term return on investment, training burdens, and limitations of knowledge transfer between locations (Burritt et al., 2020). Future research should therefore consider supplementing qualitative insights with structured data collection and financial analysis to better assess whether the benefits of I4.0T consistently outweigh their costs across MNCs' subsidiaries.

The findings may also be limited by the fact that they can only be verified in a specific sector and generalised to firms belonging to similar contexts. The current insights could be verified and compared in other sectors and geographical areas by using different methodologies.

Specifically, it would be interesting to investigate the implementation of a new BM in a group where the value chain is operationally integrated, to comprehend if, in this case, the subsidiary plays an active role in the process.

Future research should also explore the financial and organisational burdens associated with I4.0T implementation. In particular, more systematic evidence is needed to assess whether these technologies consistently yield positive outcomes or whether their success depends on complementary investments in skills, organisational culture, and governance structures.

Another future research direction would be the investigation of cost reduction resulting from the adoption of I4.0Ts for CE. This would broaden the knowledge of I4.0Ts applied for the CE and also offer a discussion on how companies can manage CE strategies to pursue better business sustainability and, simultaneously, resource optimisation (Figs. 3 and 4).

CRedit authorship contribution statement

Matteo Pozzoli: Writing – review & editing, Writing – original draft, Supervision, Formal analysis, Conceptualization. **Raffaella Nastari:** Writing – review & editing, Writing – original draft, Methodology, Data curation. **Sabrina Pisano:** Writing – review & editing, Writing – original draft, Project administration, Formal analysis. **Francesco Schiavone:** Visualization, Supervision.

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