Technological Forecasting & Social Change 213 (2025) 123995

Contents lists available at ScienceDirect

Technological Forecasting & Social Change

journal homepage: www.elsevier.com/locate/techfore

Twin transition in industrial organizations: Conceptualization, implementation framework, and research agenda

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A R T I C L E I N F O

Keywords:
Twin transition
Digital transformation
Green transition
Twin Transformation
Net-zero industry
Sustainability

A B S T R A C T

The twin transition, which involves the integration of digital and green transformations, is increasingly recognized as crucial for achieving a sustainable and competitive future. These intertwined transitions aim to decarbonize the economy by leveraging advanced digital technologies. Despite growing policy efforts to advance the twin transitions agenda and move toward a net-zero society by 2050, organizations face significant challenges in aligning digital innovations with sustainability goals. These challenges include the lack of a clear conceptualization, foundational success factors, and a structured series of activities needed to achieve the twin transition. These current shortcomings carry practical implications for implementing the twin transition and speak to the need for further research. Consequently, this study addresses these gaps by identifying the factors influencing the organizational implementation of the twin transition. To this end, we conduct a semi-structured literature review to synthesize current research on twin transitions. We provide a novel definition of twin transitions as "two parallel and mutually reinforcing digital and green transitions that amplify each other, leading to sustainable competitiveness for firms". Moreover, our analysis delineates a twin transition implementation framework, which includes triggers, organizational practices, foundational success factors, and outcomes for organizations. Our findings indicate that twin transitions are manifested through two key organizational practices: the initial stage of twin transition practices and the practices to achieve maturity in the twin transition. Furthermore, the study contributes to the growing literature at the intersection of digitalization and sustainability, providing numerous suggestions for future research and highlighting the importance of focusing on a firm-centric research agenda.

1. Introduction

Driven by the goal of reducing greenhouse gas (GHG) emissions and achieving a climate-neutral EU by 2050 through the deployment of digital technologies (Cattani et al., 2023), "twin transitions" or "twin transformations" have emerged as a political priority of the European Commission to achieve the European Green Deal (Muench et al., 2018). Twin transitions emerge from a synergetic interaction between green and digital transformations (Montresor and Vezzani, 2023; Ortega-Gras et al., 2021) to achieve a more sustainable, fair, and competitive future (Muench et al., 2018). Even though the term "transition" is broad, most of the literature shows that twin transitions are the result of the implementation of advanced digital technologies – artificial intelligence (AI), Internet of things (IoT), big data, additive manufacturing (AM), cloud computing, and robotics – to achieve sustainable and circular economy outcomes (Bianchini et al., 2023). Therefore, to achieve twin transitions, both green and digital transitions are expected to create a synergy in which one reinforces the other (Findik et al., 2023).

The term became popular in 2022 onwards in a call from the European Commission for a more "*sustainable, fair, and competitive future*" regarding green and digital transitions (Muench et al., 2018). The literature is dispersed across a wide range of scientific areas (engineering, policy making, environment, and chemistry, among others). Similarly, the variety of terms that have been used in the literature to achieve a proper understanding of twin transitions has been particularly misleading. The literature has used homogenous concepts such as

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https://doi.org/10.1016/j.techfore.2025.123995
Received 1 April 2024; Received in revised form 18 November 2024; Accepted 15 January 2025
Available online 3 February 2025

"*digitally-enabled sustainable transition*" (Spaltini et al., 2024b), "*dual transition*" (Sgambati and Carvalho, 2024), "*radical twin innovations*" (Mäkitie et al., 2023), "*green IT*" and "*IT for green*" (Montresor and Vezzani, 2023), "*twin transition* (*ecological+digital*)" (Brunori, 2022), "*digitally-enabled greening*" (Almansour, 2022), "*smart green growth*" (Fouquet and Hippe, 2022), "*circular I4.0*" *or* "*digital CE*" (Ortega-Gras et al., 2021), among others. Specifically, the term "twin transitions" is interchangeable with the term "twin transformations" in mainstream discourse and is acknowledged by leading scholars (Breiter et al., 2024; Burinskienė and Nalivaikė, 2024; Christmann et al., 2024).

While work on the topic has reflected considerable efforts from a policy-oriented perspective (Meijer, 2024), we specifically argue for a detailed examination of insights regarding twin transitions at the business level. The twin transition at the organizational level is highly intricate (Veit et al., 2024). Work on it is currently limited, addressing only one of many dimensions of the twin transition pathway and focusing on a single sector (e.g., energy) (Benedetti et al., 2023) or one type of sustainability dimension (e.g., reducing carbon emissions) (M. Rehman et al., 2024). It is evident there is a lack of understanding in the literature of what twin transitions are (Benedetti et al., 2023; Bianchini et al., 2023). Notably, this concept has been approached as a regional phenomenon guided by political-public strategies, rather than one that needs to be addressed from within the organization (Hofmann Trevisan et al., 2024). Since companies are trying to push sustainable and circular economy goals through their business models (Sjödin et al., 2023), there is a pressing need to better understand how twin transitions unfold at the organizational level (Christmann et al., 2024). Although discussions on twin transitions are gaining popularity and attracting increased scholarly attention (Ferlito, 2024), a comprehensive synthesis that moves beyond mere buzzword adoption in organizations is still under construction (Veit et al., 2024). To address this gap, our study conducts a semi-structured literature review exploring the interaction between green and digital transitions at the company level. We focus specifically on answering the following research questions:

RQ1. *What is the synthesis of the current literature on twin transitions for organizational transformation?*

RQ2. *What are the antecedents, organizational practices, outcomes, and foundational success factors for twin transition implementation in organizations?*

We seek to conceptualize twin transitions and consolidate insights and implementation practices while offering an interpretation for businesses that promotes a better understanding of how the twin transition agenda has been implemented. The review finds that focusing on green and digital transformation provides a unifying perspective on the literature on twin transitions. Using a qualitative thematic analysis, our study highlights five thematic areas relating to: *i*) the origin and definition of the twin transition concept, *ii*) organizational antecedents for twin transitions, *iii*) organizational practices for twin transition implementation, *iv*) twin transition outcomes, and *v*) twin transition success factors.

Our review findings offer valuable insights on strategic and innovation management research at the intersection of digitalization and sustainability. First, we present a firm-centric perspective on twin transitions, viewing them as a profound process of organizational change in which companies must align with emerging regulations and technologies to meet global sustainability goals and agendas. Second, we explore the synergetic and mutually reinforcing relationship between digital and green transitions, emphasizing how their interplay can be understood as a process-based twin transition journey for organizations. Finally, by focusing on the organization as the key actor in navigating the twin transitions, we identify the most impactful practices that enable organizations to fully implement this transformation. Our findings contribute both theory and practice to the literature, and we suggest potential avenues for future research.

The remainder of the paper is structured as follows. After introducing twin transition gaps and their origins, we present the research methodology in Section 2. Then, we present the results of the literature review in Section 3, further analyzed and thematically classified. In Section 4, we discuss the study's findings, draw our conclusions, and consider future research questions in the field.

2. Methodology

Given that twin transitions have been discussed in a fragmentary manner in different disciplines (Muench et al., 2018), using a systematic literature review may not be the appropriate methodology to rescue the discussion that has been developing in the domain. Therefore, we consider a semi-structured literature review to be more appropriate because it allows for a better scoping of the existing literature and helps to identify prominent topics and their evolution (Snyder, 2019). Since this study aims to synthesize the body of knowledge on twin transitions, we believe a semi-structured literature review is well suited to the task (Breslin and Gatrell, 2023). In addition, semi-structured literature reviews facilitate an analysis of content in combination with a thematic content analysis (Snyder, 2019).

Two searches were conducted in the SCOPUS database in September 2024 because it is a trustworthy and reliable database indexing journals and publications relevant to twin transitions research (Oluleye et al., 2023). Search one was carried out by using the keywords (TITLE-ABS-KEY ("twin transition" or "twin transformation")) and spawned 200 records in Scopus. Search two was developed using the terms (TITLE-ABS-KEY ("digital transition" OR "digital transformation") AND TITLE-ABS-KEY ("green transition" OR "low-carbon transition" OR "sustainable transition" OR "green transformation" OR "sustainability transition"), registering a total of 148 documents. The 348 papers were screened by the authors who evaluated each study based on three key criteria:

1. Each study should clearly focus on twin transition, in which both green and digital transitions could be identified.
2. Each study should focus on a firm level rather than a *meso* or macro level of analysis.
3. Each study should be published in a scientific journal based on peer review processes (articles and reviews).

After narrowing the results to peer-reviewed "Articles" and "Reviews", the two searches yielded 242 publications. Each study was downloaded, and documents that were not published in English, that were purely technical papers (e.g., engineering focus), and that were not available in full text were excluded. Additionally, 12 duplicate documents from the two searches were removed. Each author carefully reviewed the remaining documents to select the final set of relevant documents (Breslin and Gatrell, 2023). Following a thorough full-text evaluation, the sample was refined to 82 documents, which were analyzed to extract relevant data for the study. Appendix 1 provides a comprehensive list of the selected papers, including the authors, document titles, and the journals in which they were published. The overall research process, along with the keywords, inclusion and exclusion criteria, and study structure, is outlined in Fig. 1.

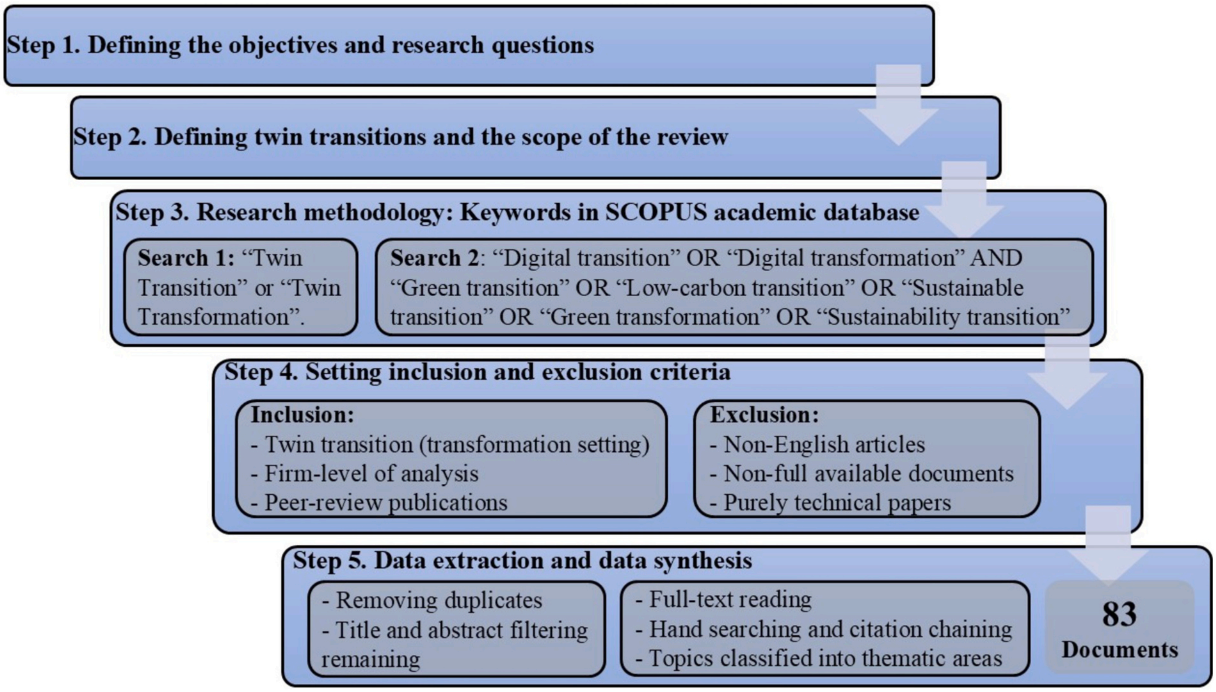

Fig. 1. Systematic literature review methodology used in the study

3. Findings

The selected documents were examined for our topic of interest. Open codes were categorized into themes, which were posteriorly classified into thematic areas. The thematic areas revealed particularities regarding: i) *The origin and definition of twin transition*, ii) *Organizational antecedents to twin transitions*, iii) *Organizational practices for twin transition implementation across maturity stages*, iv) *Twin transition implementation outcomes*, and v) *Foundational success factors*. The authors discussed the codes, each of the categories, and their inclusion was decided by agreement of the research team members. The results of the review are structured in Section 3 and summarized in Fig. 3.

3.1. Origin and definition of twin transitions

The emergence of *twin transitions* (European Commission, 2020) was envisioned as a strategy of economic policy to be carried out in the long run to ensure the decarbonization and digital transformation of the global economy (Fouquet and Hippe, 2022). Twin transitions has been disseminated as a key priority of the European Commission and is driven by the digital transformation and the green transformation agendas (Fig. 2). One agenda supports the *digital transition*, which is expected to accelerate the digitalization of Europe and tackle its associated challenges through a wide range of agendas, such as the Digital Europe Programme, the 2030 Digital Compass, the EU eGovernment Action Plan, the European Interoperability Framework, the European Digital Decade 2030 Policy Program, the 2022 EU Strategic Foresight Report,

Fig. 2. A policy-oriented agenda for twin transition.
Source: Developed from the literature (Burinskienė and Nalivaikė, 2024; Chatzistamoulou, 2023; Paiho et al., 2023; Vasconcelos-Garcia and Carrilho-Nunes, 2024).

and the Digital Innovation Hubs (DIHs) (Chatzistamoulou, 2023). It should be noted that digitalization acts as an enabler of sustainable and environmental goals.

Thus, a second agenda integrates the *green transition*, supported by the European Green Deal (European Commission, 2019), whose objective is to achieve net-zero emissions by 2050. The green transition falls under the concept of decarbonization of the economy or the so-called "net-zero transition" (Montresor and Vezzani, 2023). Moreover, other policy goals at the European and global levels are precursors of the green transition – notably, the "Fit for 55" Climate Package, Circular Economy Action Plans of the European Union, and a diverse range of environmental planetary goals summarized in the Paris Climate Agreement, the National Energy and Climate Plans, the Resource Efficiency Flagship Initiative, and the Sustainable Development Goals (SDGs) (Paiho et al., 2023).

Beyond this political debate, twin transition is considered the umbrella term that mutually reinforces green and digital transitions (Kirov, 2023). These two agendas are considered complementary (Dabbous et al., 2023). While digital provides more evidence to support green transitions, most of the literature highlights the synergy between the green and the digital because of the capacity of each to leverage the other (Ogrean and Herciu, 2021). While digital transformation is defined as "a key term to express organizational changes influenced by digital technologies" (Feliciano-Cestero et al., 2023, p. 2), green transitions are referred to "*to the means of fulfilling the European Green Deal (EGD) goals. These means include, e.g., the supply of clean energy, industries utilizing circular economy practices, a toxic-free environment, preservation of ecosystems and biodiversity, and acceleration of smart mobility*" (Paiho et al., 2023).

While both digital and green transitions are becoming more popularly recognized as a "twin transition", the term is yet to find an anchor in the literature. Table 1 shows the different concepts that have been used in the literature to define twin transitions. Three interpretations of the concept stand out. The first line of definitions adopts the common view of interpreting digital transformation as a path to achieve low-carbon (Vasconcelos-Garcia and Carrilho-Nunes, 2024), environmental (Spaltini et al., 2024b), and climate-change actions in support of business goals (Spaltini et al., 2024b). In this regard, Ogrean and Herciu (2021) describe digitalization as a catalyst for the development of related digital and sustainable developments leading to "*smart businesses*". In this streamlining, the implementation of digital technologies and green technological innovations serves as an enhancer of sustainability outcomes and environmental impact metrics (Sjödin et al., 2023). Thus, twin transition is regarded as a type of digitally-enabled green sustainable transition (Spaltini et al., 2023) with the potential to impact a firm's commitments to the environment (Rahnama et al., 2022).

The second set of definitions emphasizes the complementary interconnectedness and synergetic occurrence (Perossa et al., 2023) between digital and green transitions. While some authors have highlighted the indivisible relationship between each other (Spaltini et al., 2024a), most authors agree on the combination (Paiho et al., 2023) and simultaneity (Ogrean, 2023) of carrying green and digital transitions because of their capacity to reinforce (Findik et al., 2023) and complement each other (Rehman et al., 2023). A third set of definitions underlines the potential of transformations that twin transitions can bring to society and the organization (Bianchini et al., 2023) through adding value (Christmann et al., 2024). This line of definitions highlights the potential to tackle sustainability challenges but, at the same time, generate changes in organizational culture (Jurmu et al., 2023). This line of definitions considers twin transitions as a vehicle to accelerate the necessary changes for a more sustainable society (Muench et al., 2018). Given the variety of definitions and the lack of consensus among scholars, we define twin transition as: "*two parallel and mutually reinforcing digital and green transitions, which amplify each other leading to sustainable competitiveness for firms*".

Table 1
Compilation of definitions of twin transitions in the analyzed literature.

Author	Definition
(Vasconcelos-Garcia and Carrilho-Nunes, 2024)	"The digital shift complementing the transition towards low-carbon practices" (p. 245).
(Brueck, 2024)	"Twin transition might be achieved through the coupling of green and digital technologies, with the goal that digital applications can facilitate and accelerate GT [green technologies], whereas the green transition can, in turn, shape the priorities and objectives of digital technological innovation" (p. 45).
(Spaltini et al., 2024b)	"Digitally-enabled configurations of operations processes to achieve both business and environmental goals" (p. 2).
(Spaltini et al., 2024a)	"Twofold and indivisible transitions, sustainable and technological, as Twin Transition (TT)" (p. 2).
(Christmann et al., 2024)	"A twin transformation refers to a value-adding interplay between digital and sustainability transformation efforts that improve an organization by leveraging digital technologies for enabling sustainability and leveraging sustainability for guiding digital progress."
(Perossa et al., 2023)	Twin transition… "strives to implement and exploit digital technologies to improve the environmental sustainability of companies" (p. 1). "The TT defines the synergetic occurrence of Digital Transition (DT) and Green Transition (GT)."
(Paiho et al., 2023)	"The combination of digital technologies and European Green Deal goals, to achieve sustainable solutions supporting the creation of impactful, net-zero carbon and a resilient built environment" (p. 1).
(Rehman et al., 2023)	"Refers to an intertwined and simultaneous green and digital transition to offset companies' carbon footprint. Therefore, companies operate under the assumption that digital technologies can help their sustainability efforts" (p. 1).
(Findik et al., 2023)	"Synergies are particularly important in Europe, given that both the digital and the green transitions are Europe's strategic political priorities, and the "twin" transitions are expected to reinforce each other" (p. 1).
(van Erp and Rytter, 2023)	"Twin Transition: a sustainable and digital transition of the industry […] as an industrial strategy in the future" (p. 92).
(Bianchini et al., 2023)	"Digital and green transformations – the so-called "twin" transition" (p. 877).
(Spaltini et al., 2023)	"Twin Transition (TT), namely a digitally enabled sustainable transition of processes and products" (p. 1).
(Mouthaan et al., 2023)	"'Twin transitions' … ought to foster a 'green digital transformation'" (p. 1).
(Montresor and Vezzani, 2023)	"The green and digital transitions are thus linked, and so intrinsically linked to be considered as 'twin transitions'" (p. 766).
(Jurmu et al., 2023)	"This twin transition is translated as the need to increasingly tackle sustainability challenges and to change corporate culture towards sustainable principles, while utilizing digitalization – understood here as highly malleable compositions of established key enabling technologies such as IoT, cloud, AI, and data management in general – in the process" (p. 1).
(Ogrean, 2023)	"The twin transition pertains to the simultaneous (and ideally reinforcing one another, despite their incongruencies) transformation towards sustainability and digitalization of businesses/organizations and the society at large – specifically by capitalizing the capacity of digital technologies to enable and accelerate the transition towards the sustainability goals – in search of a green and digital future" (p. 337).
(Rahnama et al., 2022)	"The digital transformation can positively impact firms' commitments to environmental sustainability" (p. 1).

(*continued on next page*)

Table 1 (*continued*)

Author	Definition
(Husain et al., 2022)	"Twin transition strategy enforces the indisputable complementary relationship between green and digital transitions" (p. 1).
(Ogrean and Herciu, 2021)	"The two transitions can leverage on one another – which suggests the need for an integrated approach, able to capitalize on both the 'sustainable digitalization' and the 'digital sustainability' of products/services, processes or business models" (p. 294).

3.2. Organizational antecedents to twin transition

Which conditions influence corporations to move toward twin transition processes? Scholars have identified various motivations for corporations to start a twin transition at an organizational level related to digital and green transformation (Cattani et al., 2023; Guang-lin and Tao, 2022; Korucuk et al., 2022). Antecedents are multifaced aspects where companies are compelled to launch and leverage a process toward twin transition transformation. We identified four key themes of interest relating to organizational antecedents of twin transitions: (a) *Changing policies and regulations*, (b) *Emerging green technologies*, (c) *Dynamic external environment*, and (d) *Organizational strategic drive for growth*.

3.2.1. Changing policies and regulations

For companies engaging in twin transitions, policies and regulations are critical drivers. Twin transitions are widely recognized as a key strategic priority in Europe's political agenda (Findik et al., 2023). The literature has stressed the significant role that policies play in driving the industrial strategy of the European Union (Korucuk et al., 2022), keeping EU countries at the forefront of transition efforts (Ortega-Gras et al., 2021). By fostering an environment where digital and green transitions are prioritized together, these policies encourage companies to align with broader sustainability goals (Paiho et al., 2023). Therefore, many companies are taking advantage of the use of green technologies to comply with regulations (Brueck, 2024). Companies have responded positively to twin transition motivations because countries are eager to create climate policies and a safe investment environment (Husain et al., 2022). This is highlighted by a growing number of studies originating from China, many of which reference the take-off of twin transitions in the country. The PRC has been supporting low-carbon pilot policies (Chen et al., 2024), environmental regulations (Dong et al., 2024), environmental taxation systems, and law enforcement to accelerate digital transformation (Liu et al., 2024a). In fact, in China, the role of market-based environmental regulation tools, such as the carbon market, has been influential in getting companies to invest in green innovations (Wang and Dou, 2023). Gao and Huang (2024) demonstrate that addressing the goals of twin transitions has led to a reduction in economic policy uncertainty for companies embarking on this transformation. In addition to twin transition policies, other regulatory measures have separately targeted the digital and green transitions, such as policies supporting green transformation (Zhao et al., 2024), energy policies (Vasconcelos-Garcia and Carrilho-Nunes, 2024), and various European digital strategies (Cattani et al., 2023).

3.2.2. Emerging green technologies

The emergence of new green and sustainable technologies has become central for companies engaging in twin transitions (Burinskienė and Nalivaikė, 2024; Guo et al., 2024). This has driven green technology innovation (Guang-lin and Tao, 2022; S. Wang and Chang, 2024) in companies and has stimulated innovation development in AI at national levels (Brueck, 2024). A contextual factor in the spread of green technologies has been the need to share information and to create technology tools that allow the sharing of essential data to operate technologies with sustainable outcomes (Jurmu et al., 2023). The creation of new green technologies has created new market opportunities for companies seeking to position themselves in more sustainable markets, facilitating the business potential of their twin transition (Cattani et al., 2023). Certain green technologies, closely linked with digital transformation – such as AI, IoT, and blockchain – enhance the efficiency of sustainable processes and serve as key antecedents of the twin transition. Finally, studies have shown that previous experience in environmental technology development (e.g., AI technology) makes it easier to apply new AI to green technologies (Brueck, 2024).

3.2.3. Dynamic external environment

The dynamic external environment, particularly digitalization (Jurmu et al., 2023), has become a central antecedent driving the twin transition. Key factors highlighted in the literature include increasing global pressures to address climate change, heightened customer awareness, and the emergence of new actors in the industry. A significant driver has been the growing global demand to reduce the environmental impact. This has exerted pressure on corporations to develop solutions to mitigate the climate crisis (Zheng et al., 2024). These solutions aim to address issues such as pollution and resource scarcity (Spaltini et al., 2024b), the depletion of natural reserves (Ruan et al., 2022), and the degradation of regional ecosystems (Zhao et al., 2024). Additional external pressures stem from consumers who are increasingly seeking products and services with a lower carbon footprint (Kekkonen et al., 2023; Korucuk et al., 2022; Zhang et al., 2023b). As markets mature (Paiho et al., 2023), companies are facing stricter environmental regulations and are expected to meet higher sustainability standards. Moreover, the entry of new market actors signals a growing competitive risk for established companies because some perceive the threat of losing market share (Zhang et al., 2023b) and may struggle to keep up with the advances of competitors (Collini and Hausemer, 2023).

3.2.4. Organizational strategic drive for growth

The company's strategic drive is a core antecedent of the firm's twin transition. In this regard, a firm's capabilities and vision (Myshko et al., 2024) and the definition of corporate objectives and strategy (Spaltini et al., 2024a) are key drivers that a company requires in order to embark on the twin transition. On the one hand, studies suggest that seeking solutions to achieve business objectives is centrally connected to transformations in leadership and working culture (Jurmu et al., 2023). Research shows that having a cognitive and moral drive to promote twin transitions (Valentinov et al., 2023) is derived from the company's central embrace of the transition and the capacity to create a climate and a digital plan (Kren and Lawless, 2023). Leadership and the company's drive have been connected to a "capability-oriented" model. Through digital capability and digital leadership, companies can capture and identify green development opportunities in the external environment (Ruan et al., 2022). A manager's green experience is a crucial form of organizational capital that significantly enhances a company's digital and green transformation processes, positioning it as a key driver of the twin transition. Additionally, embedding the twin transition in a company's strategic behavior creates incentives to achieve environmental goals by integrating green and digital technologies (Toșa et al., 2024). Some authors refer to this dimension as the adoption of a sustainability-enhancing strategy (Chatzistamoulou, 2023) or the construction of a green development strategy based on an "environment-oriented" model. These are solutions through which enterprises respond by interactively engaging organization and technology (Ruan et al., 2022).

3.3. Organizational practices for twin transitions implementation

Based on the thematic analysis, twin transitions become visible through two organizational practices: *Initial stage of twin transition practices* and the *twin transition practices for maturity stage*. The results show that organizations start their twin transition journey from different starting points in terms of the maturity of the digital transition, the potential of the implemented technology, and its capacity to support green transitions.

3.3.1. Initial stage of twin transition practices

Organizational practices for the initial-stage implementation of twin transitions are characterized by a process of company awareness and transition development (Breiter et al., 2024). Three organizational practices have been identified in this review: a) *Initiating a twin transition roadmap*, b) *Continuous evaluation of environmental impact through digital technologies*, and c) *Experimenting with new business models for twin transition implementation*. These practices are discussed in the following segments:

3.3.1.1. Initiating a twin transition roadmap. The literature has highlighted the necessity for companies to draw a roadmap of action on strategic approaches and plans to implement and integrate both digital and green transitions. To initiate a twin transition roadmap, the literature first emphasizes the importance of ***assigning readiness to adopt twin transition practices***. To assist a company's readiness and ability to embark on a twin transition, it is essential to conduct a diagnostic evaluation of its current digital capabilities and green potential. This diagnostic process is then followed by a strategic planning phase, which culminates in the development of a roadmap or implementation framework through initiatives outlining the steps the company can take to successfully navigate the transition. This stage is crucial for companies with basic levels of digital intensity (Burinskienė and Nalivaikė, 2024). According to Burinskienė and Nalivaikė (2024), the company needs to identify its twin transition status, considering its current implementation of green ICT practices to achieve environment-oriented performance. From this analysis, the company can start to integrate sustainability into the company strategy. Posteriorly, companies are expected to measure twin transition performance by constructing a multi-criteria, decision making–based, assessment framework (Burinskienė and Nalivaikė, 2024).

Gerlitz and Meyer (2021) propose conducting a digital readiness assessment or digital audit to analyze the company's digital maturity and areas for improvement. The authors refer to the need to initiate a gradual transition, implementing technologies that offer quick and tangible benefits ('easy gains') for the digitalization and sustainability transition. Regarding the relevance of adequate implementation of twin transitions, the authors highlight that managers "*shall, first of all, tackle digital and environmental transition on a management and strategic level*" (Gerlitz and Meyer, 2021, p. 19). Gerlitz and Meyer (2021) recommend integration of the 'circular readiness index' tool, which is used to assess how companies incorporate circular economy principles, and the necessary digital transformation required to support their implementation. Therefore, initiatives and project implementation stand at the forefront of the twin transition process. Lanfranchi et al. (2023) contend that the successful implementation of green and innovative projects depends on companies' readiness and commitment to adopting and promoting initiatives aligned with the twin transition. Van Erp and Rytter (2023) present an integrated "design and operations framework", which begins with a preliminary phase that includes a maturity assessment of business capabilities for digital and circular manufacturing systems. Similarly, Chen et al. (2023) introduce a framework for digitalization that enhances environmental sustainability by leveraging IoT to enable lean production.

While these studies highlight the need to develop readiness and capability diagnostics to initiate twin transitions, a significant number of studies propose the creation of roadmaps as a strategic planning tool to support the transition process (Spaltini et al., 2024a). Whereas Spaltini et al. (2023) propose a roadmap that visually links the twin transition process to strategic goals and operational activities, enhancing understanding and communication within the company, Findik et al. (2023) describe a roadmap development process for SMEs that encompasses short-, medium-, and long-term plans. This approach helps to identify effective applications of digital technologies and their environmental impacts, guiding their implementation in the company and revealing opportunities afforded by Industry 4.0 (I4.0) technologies. Korucuk et al. (2022) present a practical roadmap that supports green approaches for ICTs and to achieve an effective selection of digital marketing strategies for business operations. Pan et al. (2023) present a roadmapping taxonomy centered on resilience, human rights, and digital technologies to enhance supply chain resilience. Perossa et al. (2023) offer a twin-transition, cosmetic roadmapping tool designed to support companies in assessing and navigating their transition journey. According to the authors, the twin transition roadmap must include: (i) consideration of digital technologies, (ii) actions for environmental sustainability performance improvement, (iii) technical support mechanisms for practitioners, (iv) potential actions for product life cycle phases, and (v) tailored for the cosmetic industry. In conclusion, strategic planning – particularly the development of an appropriate framework for implementing technology for sustainability – is crucial. As Yuan et al. (2024) point out, the relationship between digitization and green transformation is non-linear because companies must reach a certain threshold of digitization before it can positively impact green transformation.

A second aspect of initiating a twin transition roadmap involves a company's commitment to ***investing in novel technologies***. Multiple studies have delved into the importance of a company's investment and resource allocation in research and development (R&D) to drive twin transitions (Brueck, 2024; Ortega-Gras et al., 2021; Wang and Dou, 2023). Authors such as Ortega-Gras et al. (2021) emphasize that companies should prioritize the implementation of six key enabling technologies (KETs) – AI, micro/nano-electronics and photonics, advanced materials, advanced manufacturing, life-science technologies, and security and connectivity – because these are pivotal drivers of the transition to a circular economy. Thus, investments should include a budget for R&D. Brueck (2024) examined the establishment of R&D centers by multinational enterprises (MNEs) in China, emphasizing their role in driving innovation through technology upgrades and knowledge diffusion, with a particular focus on investments in AI technologies. Lastly, Montresor and Vezzani (2023) suggest that investing in digital technologies – in particular, AI application areas – contributes to a firm's eco-innovation.

A final practice that supports a company's twin transition roadmapping is the ***launching of internal pilot projects***. Some studies have been conducted within the framework of low-carbon economy policies, where cities and regions implement pilot projects that support twin transitions at the business cluster level (Brueck, 2024; Chen et al., 2024; Liu et al., 2024b; S. Wang and Chang, 2024; Zhang et al., 2024a; Zheng et al., 2024). Moreover, on an organizational level, piloting processes have been developed as a series of experiments and new initiatives that companies introduce to break the traditional pathway of transitions (Collini and Hausemer, 2023). This roadmapping phase is characterized by the implementation of pilot simulation initiatives and pilot projects involving a digital tool that supports a production phase (Perossa et al., 2023). Piloting processes usually occur after an R&D investment process that has successfully developed concrete projects for the implementation of twin transitions (Collini and Hausemer, 2023). As Meyer et al. (2023) note, the implementation of twin transition strategies and roadmaps often emerges from ecosystemic approaches to testing new solutions. The authors illustrate this with a documented case of a pilot servitization process. Similarly, pilots are implemented to better understand the technological onboarding process that requires a twin transition process (Jurmu et al., 2023). Sjödin et al. (2024) offer an ecosystem view of launching piloting initiatives that promote the adoption and implementation of emerging technologies to support green transitions. Breiter et al. (2024) advocate the introduction of a pilot phase to support the company's twin transition strategy and the implementation of a twin transformation roadmap.

3.3.1.2. Continuous evaluation of the environmental impact through digital technologies. An essential practice in the early stages of the twin transition is the continuous evaluation of digital and sustainability impacts. This ongoing assessment enables companies to better anticipate future sustainability challenges while effectively advancing their twin transition goals. A key practice in this process is ***assessing the company's environmental impact***. This dimension has been widely documented in the literature. For example, Rehman et al. (2024) developed a mapping process called 'waste flow mapping', an assessment method used to identify waste production, which allows a company to quantify its environmental impact in the areas of resource consumption, waste generation, energy usage, and emissions. Guo et al. (2024) documented the implementation of green technology innovation to measure and reduce carbon emissions in Chinese manufacturing enterprises, while Cattani et al. (2023) highlighted the role of eco-innovation in reducing CO_2 emissions. Authors, such as Maksymova et al. (2023), stress digitalization, and in particular, IT implementation as a driving force to support industrial decarbonization. Brueck (2024) arrived at similar conclusions by documenting the incipient use of AI and other digital technologies to achieve carbon neutrality.

The continuous evaluation of digital and sustainability impacts is closely tied to the practice of ***implementing sustainability metrics***. With the advance of digital and green technologies, a growing number of studies have been discussing the need to pair digital innovations and green technologies with sustainability targets (Myshko et al., 2024; Wang and Dou, 2023). Through the implementation of a waste flow mapping assessment, Rehman et al. (2024) report a set of performance metrics that companies must establish to monitor and track environmental performance. Similarly, Mêda et al. (2023) describe digital tools embedded in mobile devices (tablets and smartphones) to support waste audits. Chen et al. (2023) document how lean production systems can be developed through I4.0 digital technologies to track, monitor, connect, and analyze the collected data to enhance different functions, such as poka-yoke, standardization, visual management, and inventory reduction. Korucuk et al. (2022) identify key indicators for sustainability and digital marketing, considering such metrics as environmental protection and energy cost reduction.

Finally, the evaluation of environmental impact using digital technologies has been related to practices ***ensuring regulatory compliance***. Studies have shown that digital transformation improves green information disclosure (Li et al., 2024) while reducing environmental uncertainty (Han et al., 2024). Twin transition practices have been implemented by leveraging digital tools that promote ESG indicator outreach and improve and enhance their performance (Zhang et al., 2024b). Different examples of using digital tools for environmental compliance have been identified in the literature. To illustrate, Almansour (2022) highlights the case of companies implementing digital tracking systems that help ports comply with environmental regulations. Other examples include corporate ESG performance disclosure systems (Wang and Chang, 2024) and ESG reporting for supply chain resilience systems (Pan et al., 2023). In this regard, multiple authors have stressed the potential for achieving the SDGs through digital and green practices (Almansour, 2022; Burinskienė and Nalivaikė, 2024; Gerlitz and Meyer, 2021; Rehman et al., 2024).

3.3.1.3. Experimenting with new business models. The third category of practices employed by companies in the initial stage of the twin transitions involves designing and experimenting with new business models. Business model innovation is regarded as a comprehensive, sustainability-enhancing process that encompasses the structural mechanisms necessary for a sustainable transition (Chatzistamoulou, 2023). Enterprises need to invest time and resources in ***testing value creation using green technologies***. "Value creation and delivery" is one of the three major components of a business model architecture (Teece, 2010). With respect to this, Sjödin et al. (2023) identified two types of AI-enabled circular business model through which companies create and deliver value. The first type focuses on augmentation and optimization solutions, while the second centers on automation and business models for autonomous solutions. Christmann et al. (2024) argue that twin transitions enable companies to enhance organizational performance by acquiring new capabilities that drive value creation. According to the authors, the alignment of digital and sustainable outside-in capabilities fosters value co-creation across industries. Value creation has also been explored in the literature concerned with the implementation of technologies that allow companies to move from offering purely physical products to combining products with services. Van Erp and Rytter (2023) explore the implementation of manufacturing systems and a servitization model that supports the twin transition by enabling the circular economy through digital value creation.

In line with the circular value-creation perspective, Toşa et al. (2024) emphasize the importance of creating value by promoting pro-environmental behavior among customers. They highlight how companies can integrate digital transformation by providing incentives to progress toward a circular economy. This approach to value creation through generating solutions that address customer needs is supported by I4.0 technologies that enable firms to organize their resources according to their needs (Findik et al., 2023). The servitization model has been explored in the literature by Meyer et al. (2023) who describe the implementation of a servitization business model to support ecosystem implementation of the twin transitions. Finally, exploring and testing value creation is linked to implementing value capture strategies through experimentation. For instance, Gerlitz and Meyer (2021) investigated the adoption of rental-based digital business models, which hold substantial potential to increase the flexibility of production and service operations in ports while simultaneously reducing production and operational costs.

It is important to note that much of the empirical literature on twin transitions, particularly concerning business models, argues that these transitions are driven by the formation of alliances, and collaborations out of which ecosystems are subsequently developed. Therefore, it is vital that companies embark on their twin transition journey by ***partnering with new actors***. Because authors acknowledge that a business journey toward twin transition requires companies to be part of a larger ecosystem of multiple actors sharing data, resources, and a common vision and purpose, companies need to partner with different ecosystem actors to experiment with new services and offerings that would not be possible to deliver in isolation (Meyer et al., 2023). In this vein, Gerlitz and Meyer (2021) highlight the need for collaborations and multi-level stakeholder engagement to overcome resource limitations and enhance the capabilities of ecosystem actors. Spaltini et al. (2023) focus on the development of public-private partnerships because they allow research to be connected with business needs. According to Sjödin et al. (2024), shifting toward new business models requires changes inside the organization, but companies must also be better prepared to undertake complex inter- and intra-organizational collaboration by creating ecosystem management capabilities. According to the authors, three ecosystem management capabilities are necessary: foresight, integration, and governance.

Finally, in the journey experimenting with new business models, firms are placing greater emphasis on ***introducing digital technologies for business model innovation***. Sjödin et al. (2023) examine how AI technologies can enable circular business model innovation in the manufacturing industry. They argue that AI's perceptive, predictive, and prescriptive capabilities significantly enhance the industry's ability to improve resource efficiency. Similarly, Ferlito (2024) developed a framework demonstrating how the demand for sustainability drives firms to implement I4.0 technologies, which act as enablers of the twin transition. This implementation leads to sustainable business model innovation across three categories: circular business models, platform business models, and as-a-service business models. Zhang et al. (2024a, 2024b) stress that business model transformation requires innovation in relevant technologies.

3.3.2. Twin transition practices for maturity stage

Successfully implementing twin transition practices is reflected in more advanced organizational activities, demonstrated by effectively operationalizing the company's strategy and aligning it with the firm overall plans and objectives (Breiter et al., 2024). Mature twin transition practices must be intertwined with the company's learning from the initial stage. Three mature twin transition practices were identified: a) *Utilizing advanced analytics for twin transition realization*, b) *Embedding twin transition in organizational strategic decision making*, and c) *Ecosystem alignment and orchestration to realize twin transition goals*. These practices are discussed in the following segment:

3.3.2.1. Utilizing advanced analytics for twin transition realization. The first category of advanced twin transition practices focuses on executing advanced analytics and data-driven technologies to support the twin transition. This involves integrating cutting-edge digital and green technologies to drive and enhance the twin transition. It has been noted that companies focus on ***implementing advanced I4.0 technologies***, such as AI, IoT, robots, automation, and smart sensors, among other technologies, to enhance sustainable operations through optimization, preventive maintenance, and efficiency, based on the use of real-time data and advanced analytics (Ortega-Gras et al., 2021). Sassanelli et al. (2023) explore the functioning of I4.0-driven circular supply chains and systems to support waste management process optimization. Findik et al. (2023) explore the positive effects of implementing I4.0 technologies, particularly their significant application of circular economy principles in SMEs. These technologies serve as digital, industrial, and environmental strategies in the European Union. A similar idea is presented by Liu et al. (2024a, 2024b) who explain how intelligent manufacturing is implemented across industrial clusters in China to refine production processes, improve product quality, and increase efficiency. By using big data, companies forecast customer needs and manage precise production plans. Miao and Zhao (2023) explore the triad of technology involving green technological innovation, digital transformation, and the organization and environment. Through this framework, companies can achieve better resource management, supply chain concentration, and transparency and governance – factors essential for attaining a high level of digital and green transformation.

Other studies focus on the relevance of implementing specific technologies according to the needs and characteristics of the industry. Oloruntobi et al. (2023) explore the digitalization process of the maritime industry and show how a wide range of digital technologies, such as smart devices, drones, augmented reality, smart ships, 5G networks, and automated and autonomous vessels, have facilitated enhanced simulated training and more efficient ports through the process of digital transformation. Rehman et al. (2024) maintain that the fashion industry can enhance lifecycle processes through the integration of real-time data analysis and IoT integration. Kumar et al. (2023) explore the concept of sustainable digitalization for circular recycling by using AI, robots, IoT, cloud computing, and data analytics as technologies that enhance waste/scrap management and recycling in the metallurgical industry. Mäkitie et al. (2023) focus on the shipping and electricity sectors and document a wide range of digital and green technologies, such as autonomous zero-emission ships, virtual power plants, and community energy storages, that are used as supporting technologies of the twin transition in each industry. Ferlito (2024) argues that the textile sector can benefit from digital transition technologies, such as big data analytics, IoT, and horizontal system integrations. Pertaining to this, Spaltini et al. (2024a, 2024b) argue for the implementation of zero-defect manufacturing production processes supported by ICT and I4.0 technologies. Finally, in an exploration of the built environment and construction sector, Paiho et al. (2023) found that energy technologies are the most applicable to support the twin transition, followed by control, monitoring, and automation technologies. The authors describe the implementation of mature technologies, such as renewable energy technologies (solar and wind), and intelligent information technologies, such as smart grids and platform services.

The use of advanced data-driven and green technologies allows companies to introduce practices that will ***integrate digital technologies for sustainable lifecycle assessment***. This relates to the integration of digital and green technologies that support the accomplishment of sustainable development and circular economy principles through a product lifecycle assessment (LCA), which can relate to design, production, and disposal. Perossa et al. (2023) propose that companies should establish mechanisms to thoroughly address sustainability aspects relevant to their industry throughout every phase of the product life cycle during the twin transition. Kumar et al. (2023) elaborate on the digitalization of tungsten carbide (WC)-based scraps for recycling and the use of Industry 5.0 tools to improve recycling processes while creating a closed loop in the product-to-scrap life cycle. Jurmu et al. (2023) examine the twin transitions process, stressing that digitalization is valuable for enhancing or transforming sustainability in both the initial and final stages of manufacturing processes. Korucuk et al. (2022) document the implementation of software that supports LCA through big data and the use of energy management platforms for monitoring and optimizing energy consumption. According to Rehman et al. (2024), digital technologies are useful for carrying out a company's LCA to quantify the environmental impact on production processes related to energy usage, resource consumption, waste, and emissions.

Finally, studies have highlighted the importance of ***deploying AI-driven platforms***, emphasizing AI's role in sustainability and sustainable AI perspectives, reflecting a company's strategic focus on leveraging AI for sustainability initiatives (Zechiel et al., 2024). AI-driven platforms are valuable for supporting climate forecasts, optimizing energy and water systems, enhancing supply chain management, and other functions that contribute to sustainability (Zechiel et al., 2024). Appio et al. (2024) explore the role of AI as a strategic catalyst for sustainable entrepreneurship, emphasizing its capacity to drive innovation and promote sustainable business practices that contribute to advancing the SDGs. Montresor and Vezzani (2023) argue that AI enhances a firm's propensity to eco-innovate and is significantly associated with big data and interactive technology domains – particularly, smart systems, advanced automatization, and collaborative robots. Ogrean (2023) highlights the importance of AI technologies in enhancing sustainable business practices, particularly in areas such as supply chain management, sustainable manufacturing, organizational talent development, leadership strategies for maintaining competitive advantage, and the use of AI modeling to achieve the SDGs. While many studies raise concerns about the environmental impact and increased energy consumption associated with digital technologies, Bianchini et al. (2023) argue that AI and additive manufacturing hold significant potential for reducing GHG emissions. In addition to facilitating innovation in circular business models, Sjödin et al. (2023) suggest that AI enhances a range of capabilities, including perception for data collection and analysis, predictive abilities that allow companies to anticipate future events, and prescriptive capabilities that help optimize processes and decision making.

3.3.2.2. Embedding twin transitions in organizational strategic decision making. Moving beyond implementing advanced data-driven and green technologies, the second category involves twin-transition, strategic decision-making on sustainable practices. This category relates to a set of business practices on the implementation of indicators and metrics, process automation, and enhanced capability building. First, it has been identified that a more mature stage of organizational strategic decision-making results from ***incorporating twin transition metrics***. This practice entails the adoption of twin transition indicators and metrics (digital and green KPIs) that reshape the organization's core objectives and support both digital and green transformation (Breiter et al., 2024). Gerlitz and Meyer (2021) examine the use of a decision-making tool for the digital and environmental transition of ports. This tool employs 38 key performance indicators (KPIs) in the areas of digital and environmental audits, including IT functionality, human capital, and information flows, among others. Korucuk et al. (2022) have developed green approach indicators and digital marketing strategies for ICTs, proposing a decision-making model in the logistics sector. This practice is also documented by Rehman et al. (2024) who developed a set of KPIs tailored to the fashion industry to ensure the company's material efficiency gains, assess the reduction in environmental impacts, and improve supply chain transparency through real-time data sources and advanced analytics. These indicators are integrated into LCA processes, allowing the organization to precisely define its objectives in terms of twin transitions. Peças et al. (2023) emphasize that implementing accountable and comprehensible KPIs through efficiency ratios is one of the four fundamental pillars enabling companies to achieve twin transitions. This approach facilitates continuous monitoring and enhancement of practices. Lin and Xie (2024) explore the use of green innovation efficiency (GIE) metrics to assess a company's capability for green innovation. This capability is crucial for Chinese companies seeking to pursue twin transitions. Finally, Hong et al. (2024) explore the impact of sustainable indicators for resource efficiency and productivity, developing a hybrid genetic algorithm that enables the measuring and monitoring of the company's capacity to minimize energy consumption for a circular supply chain.

Second, twin transition and strategic decision making is supported by ***the automation of evaluation processes***. This practice means that the company has the capacity to automate processes and implement autonomous systems that support the twin transition (e.g., autonomous vehicles, robots, and drones) (Dong et al., 2024; Liu et al., 2024a). Sjödin et al. (2023) further develop this idea by exploring automation and autonomous solutions as radical innovations of a business model that allow for extending the product lifespan, dematerializing resource consumption, and intensifying asset utilization. Sjödin et al. (2024) highlight that autonomous solutions radically transform products, services, and solutions, which help to sense business opportunities and configure capabilities on the level of the ecosystem. Paiho et al. (2023) explain the case of autonomous vehicles to understand potential use cases raised by combinations of technology to achieve sustainability. They are types of mobile battery storage that serve as mobility solutions for net-zero carbon and resilient built environments.

Finally, to develop adequate strategic decision-making for twin transitions, it was found that companies should focus on ***enhancing digital and sustainable capabilities***. To maintain alignment with the multiple demands required to implement a full twin transition process by companies, the literature has stressed the need to continue enhancing digital and corporate green growth capabilities (Pan et al., 2024). Vasconcelos-Garcia and Carrilho-Nunes (2024) explore the relationship between green research capabilities and resource efficiency to enhance eco-innovation practices for sustainability, which can result in more innovative products, processes, and organizational innovations. Breiter et al. (2024) contend that dynamic capabilities must be cultivated at every stage of the twin transition. Companies should harness their digital and sustainability-related capabilities because these are crucial for driving and sustaining the twin transition process. Christmann et al. (2024) argue that organizations must develop primary capabilities to ensure that the digital transformation is sustainable and that the sustainability transformation is digital. Additionally, the development of support capabilities is essential, which involves building inside-out capabilities to meet market needs and outside-in capabilities to anticipate market demands. The statement on capability development was also developed by Zhang et al. (2024a, 2024b), highlighting that business model transformation for the twin transition requires professional assistance from human capital with the necessary talent and experience. Bianchini et al. (2023) reinforce this idea by arguing that the ongoing transformation demands the adoption and dissemination of environmental technology capabilities, bolstered by digital technology capabilities. The authors highlight the importance of key digital ecosystem technologies, such as additive manufacturing, AI, big data, computing infrastructures, IoT, and robotics. Finally, developing capabilities to sustain the twin transitions is essential at the ecosystem level. All actors within an ecosystem must engage in ongoing knowledge sharing and creation by fostering competencies and addressing the transition challenges that emerge (Mas et al., 2024; Sjödin et al., 2024).

3.3.2.3. Ecosystem alignment and orchestration to realize twin transition goals. The third category pertains to the configuration, alignment, and orchestration of ecosystems that facilitate twin transitions. This involves ecosystems working collaboratively to establish a shared vision for effective twin transition and developing the necessary structures and dynamics to support it. Two elements were identified in this category. First, the literature highlights practices aimed at ***configuring strategic collaborations***. Ecosystem members must develop the values, principles, and shared ideas needed for the expected transition. Shared visions of the twin transition were evident in entrepreneurial ecosystems (Dabbous et al., 2023; Kirov, 2023; Secundo et al., 2024). Mas et al. (2024) stress the need to develop collaborative ecosystem models that foster, share, and create knowledge based on specific, mutually agreed principles. Their study highlights the importance of leveraging both deep and shallow digital technologies, upholding sustainability, and recognizing the value of partners' competencies. Jurmu et al. (2023) examined a manufacturing ecosystem in Finland, focusing on the federated data space concept as a critical technological foundation for the twin transition. The authors emphasize the importance of upfront investments in developing customized data models and the necessity of aligning a shared vision on data sharing. Furthermore, they underscore the need for ecosystem actors to reach a consensus on interoperability standards and address ethical concerns related to data sharing. In line with Gerlitz and Meyer (2021), ecosystems for twin transitions foster the development of goal-oriented communities marked by strong relationships that necessitate value co-creation, trust, and the sharing of competencies. According to Rahnama et al. (2022), to achieve collective twin transitions, it is necessary to develop a sustainable collaboration strategy. The authors state that synergetic values are required to forge collaborations because they can promote the transfer of resources and interactions through a combination of knowledge, specialized skills, and resources. Collaboration outcomes in ecosystems for twin transitions include product, process, and market innovation, performance improvement, and sustainability outcomes (Rahnama et al., 2022).

By configuring strategic collaborations, ecosystem actors are increasingly inclined to form expert frameworks to undertake joint projects, with a shared commitment to achieving superior innovative outcomes. Brueck (2024) explored how Chinese multinational corporations are driving twin transitions by forging innovative partnerships with interdisciplinary actors, such as companies, local and regional authorities, universities, startups, and research institutions. Mas et al. (2024) examine the creation and management of digital entrepreneurial ecosystems, where digital platforms foster collaboration among startups, industry leaders, and researchers, enabling twin transition unicorns to leverage deep technologies for societal challenges. These ecosystems empower twin transition unicorns to harness deep technologies effectively. Similarly, Gerlitz and Meyer (2021) documented the potential of ecosystems to create technological complementarities that facilitate better innovation. Rahnama et al. (2022) highlighted the need for collaborations in value constellations as a potential way to handle challenges that technology solution providers face when embarking on twin transitions. The authors stress that collaborations need to build long-term relationships with different stakeholders by sharing resources. The paper prioritizes the process of identifying collaborative partners to carry out tasks relating to the implementation, operation, and optimization of a production solution.

Second, ecosystem alignment and orchestration are closely connected to the practices involved in ***designing an ecosystem strategy***. Sjödin et al. (2024) suggest that creating an ecosystem strategy is essential to foster collaborative-based twin transition formation, with ecosystem management and orchestration playing a pivotal role at its interface. The development of capabilities facilitates the alignment and orchestration of the ecosystem through foresight, integration, and governance capabilities. Mas et al. (2024) argue that ecosystems require orchestration strategies to mitigate threats and market competition. These strategies involve fostering shared knowledge, achieving greater technological advancements, ensuring rigorous R&D, and securing funding collectively. By doing so, ecosystems can address new advancements and share competencies among ecosystem actors. Gerlitz and Meyer (2021) explore the causal relationships and interdependencies within ecosystems during twin transitions, where participants co-exist, co-create, and co-evolve in a shared environment. This interdependency involves an efficient and effective resource allocation of physical and intangible assets, knowledge, and human capital to facilitate twin creation. Similarly, configuring AI-enabled circular business models requires ecosystem practices that orchestrate value alignment, solution exploration, and value expansion (Sjödin et al., 2023).

3.4. Twin transition implementation outcomes

Several insights emerged from studying the interplay between digital and green transitions in a unified agenda of twin transitions. However, five dominant categories emerged on what are considered twin transition implementation outcomes: a) *Improved environmental impact and decarbonization*, b) *Improved decision making and resource efficiency*, c) *Green and sustainable competitiveness, productivity, and innovation*, d) *Inclusive work and reduced inequalities*; and e) *A synergistic and transforming effect*. Each of the outcomes is explored in turn.

3.4.1. Improved environmental impact and decarbonization

The literature identifies key outcomes of the twin transition, particularly its positive environmental impacts, including reduced environmental harm and decarbonization. Research highlights the twin transition's potential to support carbon neutrality (Liang and Sun, 2024) and minimize environmental impacts throughout product life cycles (Rehman et al., 2024) by advancing net-zero carbon initiatives and fostering a more resilient environment (Paiho et al., 2023). The reduction of environmental harm is especially significant for organizations and ecosystems engaged in twin transition processes because it has the potential to lessen environmental uncertainty (Han et al., 2024). Second, twin transition outcomes concerning positive environmental impacts were associated with the intention of businesses to inhibit pollution emissions (Korucuk et al., 2022; Laike and Ke, 2023) or reduce carbon emissions (Guo et al., 2024; Liu et al., 2024b; Perossa et al., 2023; Wang et al., 2023). Research has yielded evidence that companies can contribute to emission reduction through incremental twin innovations. Furthermore, sustainability-supported digital innovation contributes to emission reduction (Mäkitie et al., 2023). Twin transition practices focused on energy preservation (Zheng et al., 2024) and energy conservation (Wang et al., 2023) also support carbon emissions reduction. And certain studies advocate the development of environmental technologies to reduce GHG emissions (Bianchini et al., 2023).

3.4.2. Improved decision making and resource efficiency

Organizations can benefit from twin transitions through improved decision making concerned with enhanced resource efficiency and optimization processes (Meyer et al., 2023). Enhancement of resource efficiency through innovation is a central concern of research (Lin and Xie, 2024; Zheng et al., 2024). Firms can positively strengthen commitments to environmental sustainability (Rahnama et al., 2022) by developing environmental sustainability plans (Cattani et al., 2023). This line is related to studies that delve into resource allocation efficiency and production efficiency (Kekkonen et al., 2023) by reducing resource utilization and energy consumption (Chen et al., 2024). Hong et al. (2024) describe the case of heavy industries in China that can program decision making to minimize energy consumption in a circular supply chain. The improvement in resource efficiency is linked to an increase in the process of product life extension (Rehman et al., 2024), while decision making is related to the automation process and augmented data-driven analysis (Sjödin et al., 2023). Overall, the twin transition supports companies in augmenting green and traditional innovation efficiency (Zheng et al., 2024).

3.4.3. Green and sustainable competitiveness, productivity, and innovation

Competitiveness, productivity, and innovation are recognized as key outcomes of twin transitions as they promote companies' sustained growth. By undertaking this transformation (Christmann et al., 2024), companies enhance their competitiveness and secure long-term competitive advantages over rivals that have not embraced such transformative initiatives (Breiter et al., 2024; Ferreira et al., 2022; Lanfranchi et al., 2023; Pan et al., 2024). Some authors go deeper into the concept of *competitiveness* as organizations initiate twin transition processes. For instance, Rehman et al. (2023) argue that, through twin transitions, companies can generate green-based competitive advantages (technological innovation and green human resource management), while Dabbous et al. (2023) delve into the concept of sustainable competitiveness. In similar vein, Chatzistamoulou (2023) focuses on digital competitiveness as an accelerator of sustainability transitions. Overall, companies can enhance enterprise competitiveness (Fan et al., 2023) by relating competitiveness to eco-innovation as a promoter of ESG performance to maximize profit. Moreover, twin transitions have proven to be a catalyst of *productivity* in enterprises (Kren and Lawless, 2023; Oloruntobi et al., 2023). To illustrate, Zhang et al. (2023a, 2023b) suggest that twin transitions have a positive impact on green productivity by improving a firm's environmental management performance while simultaneously achieving economies of scale (Zhang et al., 2024a). Economic value creation is recognized as resulting from increased productivity and improved organizational performance through twin transitions (Glebova and Madsen, 2024). This idea is supported by Gao and Huang (2024), who noted that digital transformation improves firm-level, green, total factor productivity, leading to the company's growth and environmental protection.

Finally, *innovation* was identified as a crucial driver of sustained growth for companies. It is a factor that leads to superior performance on (green) technological innovation (Myshko et al., 2024; Pan et al., 2024; Yuan et al., 2024) and corporate green innovation (Han et al., 2024; Li et al., 2024; Liang and Sun, 2024; Wang and Dou, 2023), and it catalyzes eco-innovation (Cattani et al., 2023; Montresor and Vezzani, 2023; Vasconcelos-Garcia and Carrilho-Nunes, 2024). Digitally transformed processes, such as manufacturing servitization, enable companies to boost green technology innovation and optimize their operations (Wang et al., 2023). Timmermans et al. (2023) highlight industrial innovations as significant outcomes, while Meyer et al. (2023) link innovation to advancements in I4.0 technologies, supporting cybersecurity, digital system implementation, GHG emissions monitoring, and energy sharing. Additionally, innovation and eco-innovation were related to companies' potential to register patents, as an indicator of innovation in the context of twin transitions (Bianchini et al., 2023; Guo et al., 2024; Liu et al., 2024b; Ortega-Gras et al., 2021; Timmermans et al., 2023; Zhao et al., 2024). In addition, twin transitions bolster innovation through entrepreneurship, enhancing the capacity of entrepreneurs to identify opportunities and drive ecosystemic innovation (Appio et al., 2024; Ferreira et al., 2022; Secundo et al., 2024).

3.4.4. Inclusive work and reduced inequalities

One of the key outcomes of the twin transition is the promotion of inclusive work and the reduction of social inequalities (Timmermans et al., 2023). The literature highlights that the twin transition can foster decent work conditions and inclusiveness (Kirov, 2023), create more high-value jobs (Lanfranchi et al., 2023), and enhance resilience and human rights protection across the supply chain (Pan et al., 2023). Ogrean and Herciu (2021) argue that the twin transition can improve working conditions, while Veit et al. (2024) document the development of green employee behavior, which is linked to perceived organizational support for the environment and psychological ownership. This, in turn, fosters organizational behaviors, such as conservation, initiative taking, positively influencing others, and avoiding harm. Liang and Sun (2024) argue that digital transformation promotes corporate green innovation while improving human capital upgrading and environmental management. In addition, the literature emphasizes the importance of not assuming that technology will inherently bring benefits by the fact of mere implementation; it is essential to examine how its inclusion generates social value and alleviates social inequalities (Timmermans et al., 2023).

3.4.5. Synergistic and transforming effect

As an outcome, twin transitions have been identified as having a synergistic and transformative effect on both companies and society. According to the literature, the dual transformative forces – digital and green – can be effectively harnessed in specific fields, driving organizational change and societal progress (Glebova and Madsen, 2024). This synergy can accelerate the development of new products and services, enabling actors in a twin transition ecosystem to respond more swiftly to customer demands and market shifts (Mas et al., 2024). Likewise, Brueck (2024) emphasizes the mutually reinforcing effect of digital and green transformations, where digital advancements facilitate green initiatives and green transitions influence the priorities of digital transformation. This synergistic effect extends to societal implications because twin transitions are noted for their role in promoting broader systemic change (Mäkitie et al., 2023) and disrupting the sociotechnical system where the twin transition development takes place (Phan and Boge, 2023). Additionally, the implementation of I4.0 technologies under sustainable development considerations can reshape supply chain structures, promote innovation management, and contribute to societal advancement (Sassanelli et al., 2023).

3.5. Foundational success factors

Foundational success factors refer to the key elements that are essential for building a strong base, and they directly contribute to the success of twin transitions in any firm or industry. These factors influence businesses throughout the process of implementing twin transitions. Studies have highlighted several factors that can be grouped into four overarching categories: a) *Leadership commitment and vision*, b) *Capacity building and skills development*, c) *Investment in technology and innovation*, and d) *Ecosystem partnerships and relationships*.

3.5.1. Leadership commitment and vision

Undergoing digital and green transitions simultaneously, under the strategic banner of twin transitions, necessitates significant commitment from leaders coupled with a vision of the future. Burinskienė and Nalivaikė (2024) emphasize that leadership commitment is crucial because companies are expected to transform their resource productivity, make strategic investments that add technical complexity, and increase the number of digital and sustainable technologies. Different authors highlight the pivotal role of leadership in guiding the business model adaptations needed for twin transitions (Ogrean and Herciu, 2021). For example, leadership must pursue its vision by adopting AI-driven circular business models (Sjödin et al., 2023), designing servitization-based models (Meyer et al., 2023; Wang et al., 2023), or implementing business models mediated by I4.0 technologies (Findik et al., 2023). These adaptations require strong leadership to address the unique challenges posed by twin transitions (Ferreira et al., 2022). Leadership plays a central role in ensuring that necessary operational enhancements and strategic adjustments are in place (Zheng et al., 2024), and that a digital and sustainable organizational culture is cultivated (Spaltini et al., 2024b). Since twin transitions reshape the business development process (Phan and Boge, 2023), Miao and Zhao (2023) propose that leadership must evaluate changes across three levels: technology, the organization, and the environment. As organizations merge digital and green transformations, effective leadership is required to drive both "organization-led organizational synergy-driven green transformation" and "organization-led digital synergy-driven green transformation" (Miao and Zhao, 2023).

3.5.2. Capacity building and skills development

A second success factor contributing to the implementation of twin transitions at the organizational level is the development and leveraging of capacities and skills that enable effective implementation. Gerlitz and Meyer (2021) stress the need to implement strategic changes at management and governance levels. This is achieved by promoting the development of digital capacity building and IT knowledge and skills in order to manage environmental focus areas, such as energy circularity, renewable emission management, biodiversity conservation, and environmental compliance. Van Erp and Rytter (2023) suggest that twin transitions require a training phase to build new skills for stakeholders and employees who operate and maintain the manufacturing processes. The authors stress that companies must develop a training curriculum for each of the targeted groups with a specific description of the expected skills and competencies. Hofmann Trevisan et al. (2024) highlight three types of skills that support twin transitions in manufacturing companies – notably, resilience skills, digital technologies skills, and specialized/technical skills.

Capacities and skills must be reinforced over time, both at the initial stage of the twin transition and at a more mature stage (Breiter et al., 2024; Hofmann Trevisan et al., 2024). For both stages, research points to the need for organizations to continuously reflect on how they can enhance their competencies and resources to adopt I4.0 technologies and integrate sustainable strategies (Breiter et al., 2024; Spaltini et al., 2023) so that I4.0 technologies are properly implemented. Sjödin et al.

(2023) highlight the importance of the capability development and learning process, conceived as a feedback loop between the continued evolution of AI capacities and the effects of AI-enabled circular business models. Likewise, twin transition competencies are supported by training and education processes to improve skills in business agility, adaptive attitudes, scientific knowledge, IT integration, and a focus on developing the company's human talent (Chatzistamoulou, 2023). Among the prominent capabilities and skills, studies have highlighted data capabilities (Zhang et al., 2023b), ecosystem management capabilities (Sjödin et al., 2024), capabilities that relate to the digital economy and green technology innovation (Guang-lin and Tao, 2022), and internal organizational management capabilities (Han et al., 2024).

3.5.3. *Investment in technology infrastructure and innovation*

The literature highlights the need to acquire and implement suitable technological infrastructure and to develop green technologies, supported by financial investments and R&D programs. Twin transition implementation requires companies to select appropriate and specific technologies to achieve the desired sustainability outcomes (Myshko et al., 2024). Paiho et al. (2023) and Lanfranchi et al. (2023) stress the need to identify specific technologies and their combinations to achieve circular economy results. This concept is further supported by Miao and Zhao (2023) who argue that twin transitions are characterized by the implementation of "technology-led information synergy-driven green transformation" and "technology-led supply chain synergy-driven green transformation" (Miao and Zhao, 2023). Zhang et al. (2024a, 2024b) underline the necessity of acquiring green technology innovations, while other authors attach importance to the implementation of relevant digital infrastructures (Ogrean and Herciu, 2021; Timmermans et al., 2023). For instance, Ogrean and Herciu (2021) point to the need for high-speed infrastructure and cloud computing for data storage and processing. To improve technological infrastructure, Dong et al. (2024) explore the construction of smart and digital factories, whereas Phan and Boge (2023) document the need to implement scalable and easily disseminated digital technologies in various industries. Similarly, establishing appropriate technological infrastructure and acquiring green technologies require companies to develop investment processes and increase R&D expenditures (Chen et al., 2024; Kren and Lawless, 2023). This factor was emphasized in studies highlighting the need to invest in diverse AI technologies (Timmermans et al., 2023), as well as investing in digitalization and environmental sustainability (Veugelers et al., 2023) and other forms of green technology (Husain et al., 2022). It should be noted that investing in a successful twin transition should not be limited to the company or its immediate ecosystem. Attracting green investors and institutional investors is equally crucial because it signals the company's potential to achieve superior performance in sustainability and innovation (Li et al., 2024).

3.5.4. *Promoting ecosystem partnerships and relationships*

Studies have emphasized the importance of configuring ecosystems (Meyer et al., 2023; Myshko et al., 2024) and systemic collaborations as key factors in making the twin transition (Rahnama et al., 2022). The configuration and orchestration of ecosystems emerge as crucial factors in promoting sustainability robustness (Gerlitz and Meyer, 2021) as well as fostering innovation, digitalization, and sustainability (Ogrean and Herciu, 2021). Studies have confirmed that twin transition ecosystems support a community-based application of technology architecture, shared institutional architecture and governance, and the creation of marketplace-based architectures in a common socio-environmental context (Meyer et al., 2023). Specifically, ecosystem partner involvement enables the effective configuration of AI-enabled circular business models (Sjödin et al., 2023), such as formation processes for international data space adoption and data sharing (Jurmu et al., 2023) and transferable data management (Phan and Boge, 2023). Beyond the ecosystem concept, other studies have explored value networks, such as industrial clusters to reduce carbon emissions (Liu et al., 2024b), tech parks, science cities focused on green and digital technologies (Brueck, 2024), and public-private partnerships to support the development of twin transitions in industrial sectors (Spaltini et al., 2023). Miao and Zhao (2023) refer to these types of collaboration as "resource-led environmental collaborative-driven green transformation".

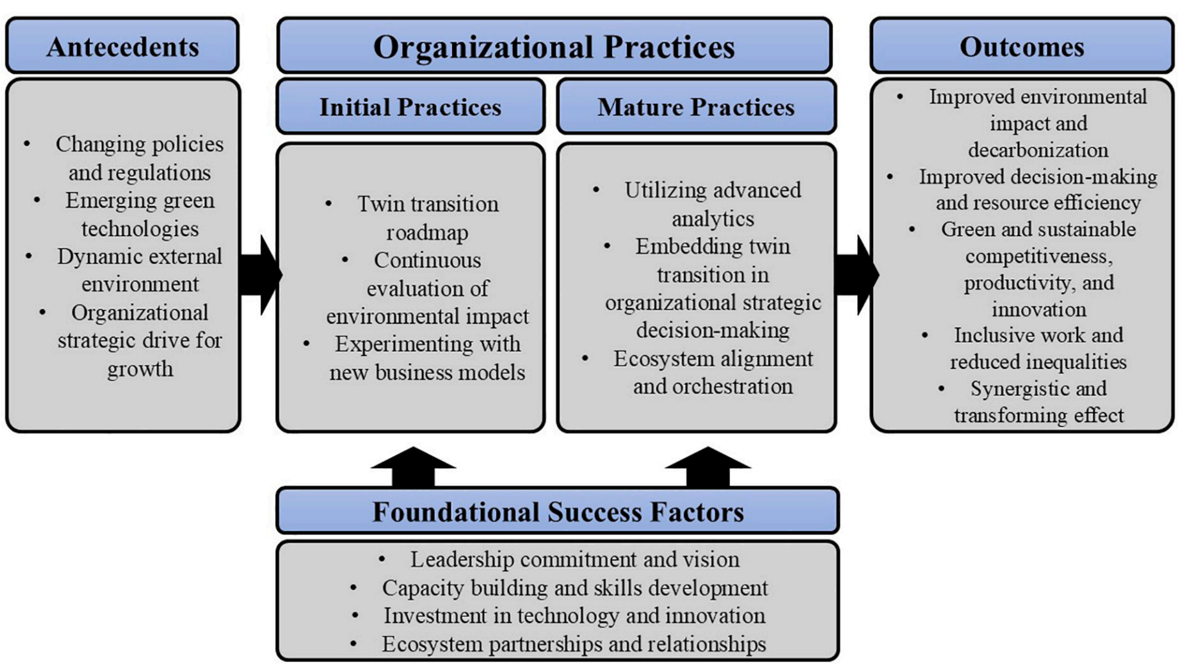

Fig. 3. A framework for organizational twin transition implementation.

4. Discussion and contributions

4.1. Theoretical contributions

First, the paper *provides a wider understanding of the emerging field of twin transitions from a firm-centric perspective*. Our paper details firms' specific insights on engaging in twin transitions because this conversation tends to be on a different level (e.g., meso and macro). Our paper emphasizes the role of organizations as agents of change in implementing twin transitions, which can enhance their competitiveness. Although regional policies are supportive, our study contributes to the emerging discussion on the advantages of adopting twin transitions from an organizational perspective, highlighting the broad benefits for companies. However, as our literature review indicates, the concept of twin transitions is still in its early stages of development at the business level and requires further exploration and experimentation on the part of organizations. To help advance understanding of the twin transitions field, we contribute by further analyzing the current empirical discussion that supports its conceptualization and analysis. By doing so, we engage in ongoing multidisciplinary conversations about the fields of digital servitization (Valentinov et al., 2023), strategic management (Sjödin et al., 2024), circular business model innovation (Sjödin et al., 2023), and transition studie*s* (Chatzistamoulou, 2023). Thus, we propose a novel definition of the concept and explain firm practices that support its achievement.

Second, our paper draws attention to *a key underlying premise for the literature that twin transitions accentuate the synergetic effect and mutually reinforcing interplay between digital and green transitions* (Glebova and Madsen, 2024). However, a close examination of this interrelationship reveals that, in the case of large manufacturing firms, digital transformation often drives green transformation rather than the reverse (Mas et al., 2024; Yuan et al., 2024). As observed in our study, digital transformation tends to dominate the research landscape, with technology frequently advancing sustainability goals. Academics and practitioners must recognize that digital and green transitions do not operate with equal intensity and can address different objectives. This brings us to a pivotal point in the twin transitions literature – previous academic studies need to be reviewed and compared because it is evident that the relationship between digital transformation and green transformation requires further clarification (Breiter et al., 2024). In this context, *digital transformation serves as the means, while green transformation represents the goal that contributes to planetary goals and policy agendas*, with both processes and their underlying motivations converging into the unified concept of twin transitions. Therefore, our study offers a theoretical perspective that helps to identify a company's optimal synergy between digital and green initiatives so that effective integration and impact are achieved. In this regard, we define the twin transition as: "*two parallel and mutually reinforcing digital and green transitions, which amplify each other, leading to sustainable competitiveness for firms*".

Third, our *study underscores the importance of identifying specific organizational practices essential for facilitating firms' twin transitions*. Therefore, our identified practices form the foundation for achieving successful twin transitions to achieve organizational competitiveness. We categorized these implementation practices into two phases: initial and mature. In the initial phase, we identified three key practices: developing a twin transition roadmap, continuously evaluating digital and environmental impacts using digital technologies, and experimenting with new business models for twin transitions. In the mature phase, organizations typically adopt practices such as employing advanced technologies for twin transitions, integrating twin transitions into strategic decision making, and aligning and orchestrating ecosystems to achieve transition goals. Therefore, our study contributes to the organizational-related discussion on twin transitions, carrying implications for business capabilities (Breiter et al., 2024; Christmann et al., 2024; Liang and Sun, 2024; Sjödin et al., 2023), ecosystem formation (Jurmu et al., 2023; Meyer et al., 2023; Secundo et al., 2024; Sjödin et al., 2024), and higher competitiveness (Brueck, 2024; Collini and Hausemer, 2023; Fan et al., 2023).

4.2. Practical contributions

Managers and practitioners embarking on twin transitions must adopt a multi-staged approach, beginning with an assessment and development of a comprehensive twin transition plan to guide the process toward full maturity. Recognizing twin transitions as a process of organizational transformation and business model innovation is crucial because it involves ecosystem formation, capability development, and the selection of appropriate mechanisms. Our study contributes by highlighting the key implementation practices for twin transitions and providing insights to help practitioners assess the preconditions needed to adapt to these processes. The implications of our findings offer valuable guidance to both small enterprises and larger incumbents, emphasizing that a thorough evaluation of digital and green transition potential is essential at the firm level. By adopting a twin transition agenda, managers can unlock significant benefits, although this will require transformative changes to business models and organizational structures. This study can serve as a resource to support, develop, and improve the twin transition journey across different industries. Similarly, this study helps managers and business practitioners find an appropriate path to initiate the twin transition process, not merely as a response to regulatory frameworks addressing climate change policies, but by adopting a more transformative approach in their niche. Our study urges them to take on the role of innovators and frontrunners, leveraging the resources available in their ecosystems to maximize opportunities and drive meaningful transformation toward decarbonization and enhanced sustainable outcomes.

4.3. Limitations and future research

Although this research addresses several issues on the development of organizational practices concerned with the implementation of twin transitions, several questions remain unanswered. We summarize key knowledge gaps and correlated research questions discussed in the results section in Table 2 below.

Table 2
Summary of future research avenues.

Future research avenues	Key gaps in knowledge	Research questions	References
Organizational antecedents to twin transitions	Changing policies and regulations	What is the impact of environmental regulations on a company's twin transition? How effective are policy measures aimed at promoting twin transitions and fostering green entrepreneurship? How do digital transition goals align with technological imbalances in EU member states that may hinder the green and digital transitions? What is the role of managers and middle managers in promoting supply chain integration to avoid economic policy uncertainty when delving into twin transitions?	(Chen et al., 2024) (Kekkonen et al., 2023) (Gao and Huang, 2024)
	Emerging green technologies	How does regional government support influence the integration of AI into green technologies in clusters and networks? What types of green technology support firms' twin transition processes?	(Brueck, 2024)
	Dynamic external environment	What is the role of customers and consumers in the market that supports a company's twin transition? How could enterprises develop new community services, data management, and intelligent solutions to open new markets that support a company's twin transition? How can companies change end users' behavior in energy conservation and efficiency and set clear targets to carry out twin transitions?	(Paiho et al., 2023)
	Organizational strategic drive for growth	What are the most impactful strategies for implementing digital and circular practices to reduce GHG emissions and promote responsible consumption and production? What are the challenges and opportunities perceived by entrepreneurs, start-ups, growing enterprises, mature companies, and different industries to pursue twin transitions? How to develop holistic and critical theories of the firm undergoing twin transitions that unveil cognitive, ethical, and moral aspects of the firm? What are the triggers of resource-based enterprises in heavily polluting industries to pursue twin transitions? How can SMEs speed up twin transition processes?	(Rehman et al., 2024) (Kekkonen et al., 2023) (Valentinov et al., 2023) (Ruan et al., 2022) (Ogrean and Herciu, 2021)
Initial stage of twin transition practices	Initiating a twin transition roadmap	What are the key project management aspects involved in the implementation phase of twin transitions? How can the social sustainability dimension be integrated into the sustainable transition process for manufacturers, adopting a triple bottom line perspective? How can a methodological framework be developed to ensure data accessibility and standardization, thereby enhancing the reliability and applicability of circularity readiness indices for twin transitions? How can a framework be designed to integrate technological relatedness and incentivize sustainability transitions in SMEs? How can roadmapping tools and methodologies validate a company's twin transition process? How can an automated mechanism be developed to customize a company's know-how in order to capitalize on that knowledge in a twin transition process? How can mechanisms be created that link different company processes with digital technologies in order to pursue sustainability outcomes? What frameworks and methodologies could empower SMEs to use roadmap tools more effectively and autonomously?	(Spaltini et al., 2024b) (Toşa et al., 2024) (Chatzistamoulou, 2023) (Perossa et al., 2023)
	Continuous evaluation of environmental impact through digital technologies	How do ESG ratings impact green technology innovation in enterprises in different sectors? How can companies from different industries implement mobile devices to support circular economy goals? What are the reasons influencing the choice of digital technologies in certain industries to support green transformations, and how do firms adopt suitable and efficient digital solutions? How can integrating IoT and related digital technologies with lean principles facilitate environmental impact reduction in production systems? How can the use of data mining support information management in SMEs to achieve sustainability outcomes? How does the use of digitalization support SMEs' intentions to contribute to the SDGs? How can companies develop individual technologies (and their sustainability) to accelerate twin transitions in non-mature markets? How can project risk management dimensions be integrated into the development of a technological roadmap for twin transitions? How can assessment frameworks be validated and strengthened through practical application in different sectors? How can data-driven models and data analytics be customized to meet the twin transition needs of different companies and sectors? How can integrating I4.0 technologies and sustainable practices in SMEs contribute to achieving the SDGs?	(Wang and Chang, 2024) (Brueck, 2024) (Mėda et al., 2023) (Findik et al., 2023) (Chen et al., 2023) (Ogrean, 2023) (Paiho et al., 2023) (Spaltini et al., 2024a) (Peças et al., 2023)

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Future research avenues	Key gaps in knowledge	Research questions	References
	Experimenting with new business models for twin transition implementation	What mechanisms can help overcome business inertia and promote more advanced stages of twin transitions? How can resource-based enterprises effectively integrate corporate social responsibility initiatives to minimize environmental pollution and resource consumption? What are the barriers and challenges organizations face when adopting and implementing AI-enabled circular business models? What is the long-term impact of AI-enabled circular business models on circular outcomes in different industrial settings? How can the creation of a market for twin transition solutions, particularly through offering services, such as integrated data management platforms, machine learning, and fossil-free energy technologies, support sustainability goals? What are the advantages and risks of collaboration in developing and implementing tailor-made technological solutions for sustainable production? How do different decision-making environments of companies integrate green approaches and digital marketing strategies for information and communication technologies to reduce environmental risks? How can entrepreneurs implement business model measures to mitigate climate change and accept the challenges posed by the digital transition?	(Sjödin et al., 2024) (Zhao et al., 2024) (Sjödin et al., 2023) (Timmermans et al., 2023) (Paiho et al., 2023) (Rahnama et al., 2022) (Korucuk et al., 2022) (Ferreira et al., 2022)
Twin transition practices for the maturity stage	Utilizing advanced analytics for twin transition realization	How can I4.0 technologies support zero-defect manufacturing for viable approaches to sustainability? How does foreign direct investment from different individual countries or regions influence eco-innovation outcomes at the country level? How can digital innovation be effectively integrated into food and mobility systems, and the circular economy, to support twin transitions? What strategies can companies employ to address twin transition complexities in achieving digital and sustainable innovation goals? How do twin transitions and sustainable digitalization unfold in enterprises implementing circular economy principles? How do digitalization and the use of technologies, such as AI, robotics, cloud computing, and data analytics, among others, promote efficient circular recycling? How do clients' attitudes and behaviors vary concerning AI for sustainability strategies? How effective are diverse AI-for-sustainability initiatives across industries with varying degrees of AI usage? What are the various AI technologies for sustainability initiatives in several research contexts? How do AI-for-sustainability strategies influence the retention and attraction of existing and future employees, and how does this impact their motivation and job satisfaction? How can small companies implement AI strategies for sustainability, given their limited resources compared to big tech companies? How do advancements in AI indirectly promote environmental sustainability, despite not being specifically designed for this purpose? How does the use of AI support SMEs' endeavors to promote food security in agriculture sectors? How can AI-driven smart farming techniques enhance the delivery and effectiveness of ecosystem services in SMEs? How do SMEs integrate AI technologies to balance productivity and environmental sustainability in their ecosystem service management? How do I4.0 technologies and circular practices interact over time in SMEs?	(Spaltini et al., 2024b) (Vasconcelos-Garcia and Carrilho-Nunes, 2024) (Mäkitie et al., 2023) (Kumar et al., 2023) (Bianchini et al., 2023) (Zechiel et al., 2024) (Myshko et al., 2024)
	Embedding twin transition in organizational strategic decision making	How can dynamic capabilities be developed in a way that respects sustainability and accounts for the environmental footprint of digital technologies? How can other capabilities frameworks contribute to a better understanding of companies' twin transitions? What novel nuances can be added to research on twin transitions from the point of view of service providers and manufacturing companies? How do businesses adopt intelligent technologies (AI, big data analytics, deep learning, and edge computing) in different segments of traditional industries for circular supply chains and migration? How can companies verify, validate, and evaluate the efficacy of decision-making frameworks to support the development of circular and digital manufacturing systems? How can companies implement suitable methods that integrate, implement, and test iterations of manufacturing systems for twin transitions?	(Breiter et al., 2024) (Hong et al., 2024) (van Erp and Rytter, 2023)
	Ecosystem alignment and orchestration to realize twin transition goals	How do ecosystems supported by twin transitions operate in practice considering different industries? What is the role of twin transition ecosystems in European sectors? How do ecosystems foster innovation for digitalization and sustainability? How do twin transition ecosystems gain new members with different capabilities and competencies? How does leadership in twin transition ecosystems connect and orchestrate	(Meyer et al., 2023) (Ogrean and Herciu, 2021) (Collini and Hausemer, 2023) (Sjödin et al., 2023)

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Future research avenues	Key gaps in knowledge	Research questions	References
		the multiple actors involved in the transition? How does ecosystem orchestration occur through leveraging the platform ecosystem to progressively target bigger sustainability goals? How do ecosystem orchestration and partnering unfold to achieve shared revenue models for AI?	
Twin transition implementation outcomes	Improved environmental impact and decarbonization	How do carbon emission reduction models differ across various industries using digital technologies? How do different levels of digital development influence green innovation efficiency when incorporating pollution-related metrics from a regional perspective? What are the specific mechanisms through which digital transformation impacts carbon emissions in high-carbon-intensity segments of an industry? What are the various mechanisms, beyond innovation efficiency, through which digital transformation can drive carbon emissions reduction? What are the challenges and potential solutions in establishing causality between digital transformation and environmental sustainability in high-carbon intensity industry segments? How does the measurement of enterprise energy conservation and emissions reduction intensity based on pollutants emitted by enterprises compare with the costs of assessing the impact of manufacturing servitization and digital transformation? How can the impact of digital input on enterprise green productivity and green transformation in manufacturing companies be measured? How can digital technology be effectively leveraged to empower the green transformation of manufacturing enterprises and create a virtuous cycle of digitalization and greening?	(Guo et al., 2024) (Lin and Xie, 2024) (Zheng et al., 2024) (Wang et al., 2023) (Zhang et al., 2023a) (Laike and Ke, 2023)
	Improved decision making and resource efficiency	How can real-time monitoring, data analytics, traceability, and transparency, as components of I4.0, be integrated into a supply chain to optimize resource utilization and enhance sustainability? Which digital technologies could be integrated into lean implementations to enhance green performance? How can shipping companies enhance operational efficiency by utilizing advancements in hardware and software to tackle challenges such as shortages in qualified personnel, increasing fuel costs, infrastructure development, and port congestion in expanding regions?	(Rehman et al., 2024) (Chen et al., 2023) (Oloruntobi et al., 2023)
	Green and sustainable competitiveness, productivity, and innovation	What are the benefits of firms' green innovations on green innovation KPIs, and to what extent can green innovations lead to green productivity? What are the environmental effects of the digital transformation on SMEs? What is the impact of digitalization and greening on enterprises' economic performance? How do socio-economic forces in different territorial contexts influence the relationship between digital innovation and eco-innovation in firms? How does the digital technology application of enterprises influence their competitiveness across different regions within a country? What are the causal relationships between an enterprise's digital technology application, ESG performance, green technology innovation, and enterprise competitiveness? To what extent does digital competitiveness influence the sustainability transition among SMEs? How does the misalignment between seaborne industry strategies and innovation hinder efforts to address critical challenges? How can twin transitions be more accurately assessed beyond patenting activity, considering the innovation strategies of firms that rely less on patent registrations? What are the short-term and long-term dynamics of the relationship between digitalization and sustainable competitiveness? What are the indirect effects of studying the relationship between entrepreneurship and sustainable competitiveness when undergoing the stages of digitalization? Should companies implement technology combinations based on the estimated leading individual technologies or build them specifically for relevant use cases to enhance sustainability? How do IoT, green human resource management, and investment in environmental management influence green competitive advantages when comparing larger corporations and SMEs? What are the longitudinal effects that IoT, green human resource management, investment in environmental management, and technological innovation have on a firm's green competitive advantages? How can green technology innovation be measured beyond the number of green patents, considering factors such as the quality and impact of these patents? What are the dynamic capabilities and financial constraints of businesses undergoing a process of green technology innovation? How do entrepreneurs secure a path toward twin transitions and overcome the lack of knowledge about the underlying concepts of sustainability and digitalization?	(Li et al., 2024) (Zhang et al., 2024a) (Han et al., 2024) (Cattani et al., 2023) (Fan et al., 2023) (Chatzistamoulou, 2023) (Oloruntobi et al., 2023) (Bianchini et al., 2023) (Dabbous et al., 2023) (Paiho et al., 2023) (Rehman et al., 2023) (Guang-lin and Tao, 2022) (Ferreira et al., 2022) (Husain et al., 2022) (Liang and Sun, 2024) (Gao and Huang, 2024)

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Future research avenues	Key gaps in knowledge	Research questions	References
		How can companies mitigate the risk of green investment while aligning business goals with the SDGs? How does digital transformation promote green innovation by capturing the evolving dynamics of economic and environmental contexts? What are the dimensions of digital transformation, such as operations, organization, digitizing products, and environment when implementing digital-related intangible assets?	
	Inclusive work and reduced inequalities	How do organizational practices, such as employee involvement in decision-making processes, feedback mechanisms, training opportunities, and pro-ecological culture, influence employee green behavior through digital technologies? What are the effective strategies for enhancing perceived organizational support for the environment among employees, thereby facilitating the twin transition? How do twin transitions impact economic inequalities, especially regarding access to resources and employment opportunities across different industries and occupations? What is the role of human rights in supply chain sustainability in the context of geopolitical tensions and the pandemic? What managerial insights are needed to address the impact of geopolitical tensions on companies' implementation of the SDGs within production systems and sustainable supply chains?	(Veit et al., 2024) (Pan et al., 2023)
	A synergistic and transforming effect	How and when do companies develop twin transitions to support or reconfigure socio-technical systems? What are the synergistic relationships between green and digital technologies, and how can each transition enhance the implementation and effectiveness of the other? What are the broader economic implications of the twin transition on economic growth, productivity, technological development, and climate change mitigation for various stakeholders at individual, ecosystem, regional, and national levels? How do twin transitions impact the production capacity and the exploitation of natural resources of companies in developing countries? How does the adoption of blockchain technology impact the environmental, social, and economic effects of running a twin transition? How do the transaction costs of an industrial symbiosis network vary during its deployment phase before and after the implementation of blockchain technology for twin transitions? How do digital and green technologies synergistically reduce firm-level air and GHG emissions, and what are the mechanisms driving these synergies?	(Mäkitie et al., 2023) (Timmermans et al., 2023) (Sassanelli et al., 2023) (Bianchini et al., 2023)
Foundational success factors	Business model innovation and organizational change	How can circular business model innovation catalyze organizational change that fosters twin transitions? How does organizational adaptation occur in response to the challenges posed by the digital and green transitions?	(Sjödin et al., 2024) (Ferreira et al., 2022)
	Leveraging twin transition capabilities and skills	How can training programs be developed and skills prioritized to meet the evolving demands of contemporary organizations? How do practitioners perceive the skills and job profiles necessary to facilitate the twin transition, and to what extent are these skills reflected in current educational offerings? How do ecosystem management capabilities influence firm and ecosystem financial performance and innovation outcomes? What capabilities and enablers are required to manage ecosystem relationships in different contexts on a cross-actor level? How do the capability requirements for ecosystem management vary at different stages of ecosystem evolution? How do non-linear effects of digital transformation influence green innovation, and how do internal factors, such as managerial knowledge, impact this relationship? How can digital technology facilitate the outsourcing of business modules in manufacturing enterprises to enhance sustainability? How can management capabilities promote green technology innovation in manufacturing enterprises from different geographies and industries? How can management capabilities be enhanced to leverage the digital economy and green technology innovations, and what improvements are needed in the indicators used to measure the digital economy? What management capabilities are essential to foster innovation in green technology in the digital economy, and how can these capabilities be assessed?	(Hofmann Trevisan et al., 2024) (Sjödin et al., 2024) (Han et al., 2024) (Zhang et al., 2023b) (Guang-lin and Tao, 2022)
	Technology infrastructure, green technology, and financial investment	How can innovation capabilities in the management of key technologies be improved? How do uncertainty and access to finance affect investment decisions in the context of the rapid evolution of digital and climate-friendly technologies during twin transitions? How can resource-based enterprises collaborate with financial institutions to develop and utilize sustainable financial products and services that support digital and green transformation?	(Dong et al., 2024) (Kren and Lawless, 2023) (Zhao et al., 2024) (Miao and Zhao, 2023) (Paiho et al., 2023) (Ortega-Gras et al., 2021)

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Future research avenues	Key gaps in knowledge	Research questions	References
		What are the key factors influencing the green transformation of enterprises, and how can these be analyzed? How do digital technologies facilitate green transformation and technological innovation in enterprises? To what extent can investment in digital technologies mitigate climate change and promote environmental sustainability? How can digital technologies for sustainability be adapted to local contexts while maintaining scalability across different regions? What strategies facilitate the diffusion and adoption of digital solutions for sustainability in traditional location-specific industries? What are the exact technology and technology combinations that enterprises require to support twin transitions? How can different I4.0 technologies foster circular economy practices through detailed research on each of the I4.0 technologies? What technologies, apart from big data, AI, IoT, robotics, and AM, could support the circular twin transitions in different industry sectors?	
	Twin transitions ecosystemic thinking	How can ecosystem transformations be achieved that allow the alignment of interdependent actors so that twin transitions can be promoted through persistent multi-actor interplay? How can industrial cluster development promote green transformation and enhance digital competitiveness? How can green procurement practices be effectively implemented to reduce the environmental impact of the supply chain and encourage sustainability in an ecosystem? How does digital transformation promote employment creation and inclusive work in entrepreneurial ecosystems? How can common interfaces be implemented that facilitate the development of a digital ecosystem supported by twin transitions? How can companies of different sizes in ecosystems develop capabilities to carry out IT integration projects for international data space adoption? How do ecosystem theories explain twin transition research? How do ecosystems facilitate the servitization process in the context of twin transitions? How can collaboration between the scientific and industrial sectors facilitate the convergence of green and digital transitions in achieving a twin transition? What are the characteristics of circular supply chain dynamics in developed and emerging economies pursuing twin transitions? How do multiple case studies contribute to understanding the benefits, opportunities, and barriers associated with circular supply chains in different industries undergoing twin transitions? How can transferable data in a late-stage ecosystem of a digitalized industry be managed to provide solutions and novel products? How can case studies inform the role of public-private partnerships in fostering twin transitions? How can ecosystem interactions that support twin transitions be explained by considering concepts such as social responsibility and the impact of social performance indicators? How do different sustainability pillars and actors in an ecosystem result in either positive or negative reciprocal relationships toward twin transitions?	(Liu et al., 2024b) (Kirov, 2023) (Jurmu et al., 2023) (Meyer et al., 2023) (Kekkonen et al., 2023) (Sassanelli et al., 2023) (Spaltini et al., 2023) (Gerlitz and Meyer, 2021)

CRediT authorship contribution statement

Sabrina Tabares: Writing – review & editing, Writing – original draft, Investigation, Formal analysis, Data curation, Conceptualization. **Vinit Parida:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis. **Koteshwar Chirumalla:** Writing – review & editing, Writing – original draft, Supervision, Investigation, Conceptualization.

Acknowledgements

We are grateful for the financial support from the Swedish Energy Agency (P2021-90100) and The Research Council of Norway (326087), which enabled us to conduct this study. In addition, the work was supported by the Circul8 (Smart Battery Circularity) project funded by the Knowledge Foundation in Sweden (1602, 2019).

Appendix I. List of papers included in the study

#	Authors	Title	Source title
1	(Hofmann Trevisan et al., 2024)	Skills for the Twin Transition in Manufacturing: A Systematic Literature Review	Journal of Cleaner Production
2	(Burinskienė and Nalivaikė, 2024)	Digital and Sustainable (Twin) Transformations: A Case of SMEs in the European Union	Bulgarian Journal of Agricultural Science
3	(Wang and Chang, 2024)	A Study on the Impact of ESG Rating on Green Technology Innovation in Enterprises: An Empirical Study Based on Informal Environmental Governance	Journal of Environmental Management
4	(Ferlito, 2024)	Industry 4.0 and Sustainability: The Case of the Italian Textile District of Prato	Competitiveness Review
5	(Christmann et al., 2024)	The Twin Transformation Butterfly: Capabilities for an Integrated Digital and Sustainability Transformation	Business and Information Systems Engineering
6	(Li et al., 2024)	Digital Transformation Driving Green Innovation: Evidence from Chinese A-Share Firms	International Review of Economics and Finance
7	(Liang and Sun, 2024)	Does Digital Transformation Promote the Green Innovation of China's Listed Companies?	Environment, Development and Sustainability
8	(Wang and Dou, 2023)	Investigation on How Carbon Markets and Digital Transformation Affect Green Innovation: Evidence from Chinese Listed Companies	Environment, Development and Sustainability
9	(Gao and Huang, 2024)	Digital Transformation and Green Total Factor Productivity in the Semiconductor Industry: The Role of Supply Chain Integration and Economic Policy Uncertainty	International Journal of Production Economics
10	(Yuan et al., 2024)	Digitalization Drives the Green Transformation of Agriculture-Related Enterprises: A Case Study of A-Share Agriculture-Related Listed Companies	Agriculture (Switzerland)
11	(Breiter et al., 2024)	Dynamic Capabilities for the Twin Transformation Climb: A Capability Maturity Model	Information Systems Frontiers
12	(Appio et al., 2024)	Pairing AI and Sustainability: Envisioning Entrepreneurial Initiatives for Virtuous Twin Paths	IEEE Transactions on Engineering Management
13	(Mas et al., 2024)	Combining Deep and Digital Technologies as a Path Towards Twin Transition: The "Future Farming" Case Study	IEEE Transactions on Engineering Management
14	(Secundo et al., 2024)	An Entrepreneurial University Ecosystem for Sustaining the Twin Transition Through a Complex Adaptive System Approach	IEEE Transactions on Engineering Management
15	(Hong et al., 2024)	Towards Sustainable Production with Resource Efficiency: An Empirical Study of Steelmaking Continuous Casting Scheduling	Resources, Conservation, and Recycling
16	(Chen et al., 2024)	Can Urban Low-carbon Transitions Promote Enterprise Digital Transformation?	Finance Research Letters
17	(Pan et al., 2024)	Climate Policy Uncertainty and Entrepreneur Eco-Investment Behavior for Green Growth – Moderate Effect Analysis of Twin Transition	IEEE Transactions on Engineering Management
18	(Sjödin et al., 2024)	Conceptualizing Ecosystem Management Capabilities: Managing the Ecosystem-organization Interface	Technological Forecasting and Social Change
19	(Spaltini et al., 2024b)	Development and Implementation of a Roadmapping Methodology to Foster Twin Transition at Manufacturing Plant Level	Computers in Industry
20	(Dong et al., 2024)	Digital Transformation and Corporate Green Innovation Forms: Evidence from China	Journal of Environmental Planning and Management
21	(Zhang et al., 2024a)	Digital Transformation by Firms and the Cleanliness of China's Export Products	Energy Economics
22	(Toșa et al., 2024)	Digital Transformation, Incentives, and Pro-Environmental Behaviour: Assessing the Uptake of Sustainability in Companies' Transition Towards Circular Economy	Sustainable Production and Consumption
23	(Kren and Lawless, 2023)	Firm-Level Attitudes and Actions to the "Twin Transition" Challenges of Digitalisation and Climate Change	Economic and Social Review
24	(Guo et al., 2024)	How Does the Digital Transformation Affect the Carbon Emissions of Manufacturing Enterprises in China? The Perspective of Green Technology Innovation	Sustainability (Switzerland)
25	(Zechiel et al., 2024)	How Tech Companies Advance Sustainability through Artificial Intelligence: Developing and Evaluating an AI x Sustainability Strategy Framework	Industrial Marketing Management
26	(Lin and Xie, 2024)	Impact Assessment of Digital Transformation on the Green Innovation Efficiency of China's Manufacturing Enterprises	Environmental Impact Assessment Review
27	(Liu et al., 2024a)	Impact of Environmental Taxation on Financial Performance of Energy-Intensive Firms: The Role of Digital Transformation	Emerging Markets Finance and Trade
28	(Liu et al., 2024b)	Industrial Clusters and Carbon Emission Reduction: Evidence from China	Annals of Regional Science
29	(Vasconcelos-Garcia and Carrilho-Nunes, 2024)	Internationalisation and Digitalisation as Drivers for Eco-innovation in the European Union	Structural Change and Economic Dynamics
30	(Zheng et al., 2024)	Is it Possible for Semiconductor Companies to Reduce Carbon Emissions through Digital Transformation? Evidence from China	International Journal of Production Economics
31	(Zhao et al., 2024)	Path Analysis of Digital Development on the Green Industrial Transformation of Chinese Resource-based Enterprises	Resources Policy
32	(Rehman et al., 2024)	Sustainable Fashion: Mapping Waste Streams and Life Cycle Management	Journal of Cleaner Production
33	(Zhang et al., 2024b)	The Impact of CEO's Green Experience on Digital Transformation	Pacific Basin Finance Journal
34	(Brueck, 2024)	The Role of Foreign MNEs in China's Twin Transition: A Study on the Organization of Green and Digital Innovation Processes	Competitiveness Review
35	(Spaltini et al., 2024a)	Toward a Technology Roadmapping Methodology to Enhance Sustainable and Digital Transition in Manufacturing	Production and Manufacturing Research
36	(Myshko et al., 2024)	Towards the Twin Transition in the Agri-food Sector? Framing the Current Debate on Sustainability and Digitalisation	Journal of Cleaner Production
37	(Veit et al., 2024)	Twin Transition in Practice: How Digital Technologies Promote Employee Green Behavior	Gruppe. Interaktion. Organisation. Zeitschrift fur Angewandte Organisationspsychologie
38	(Han et al., 2024)	Unraveling the Impact of Digital Transformation on Green Innovation through Microdata and Machine Learning	Journal of Environmental Management
39	(Montresor and Vezzani, 2023)	Digital technologies and eco-innovation. Evidence of the twin transition from Italian firms	Industry and Innovation
40	(Collini and Hausemer, 2023)	Place-based Pathways for the Twin Transition: The Role of Systemic Change Agents	Competitiveness Review
41	(Kirov, 2023)	Decent, Inclusive, and Green? Mission Impossible?	Social Sciences

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#	Authors	Title	Source title
42	(Mäkitie et al., 2023)	Digital Innovation's Contribution to Sustainability Transitions	Technology in Society
43	(Mêda et al., 2023)	Exploring the Potential of iPad-LiDAR Technology for Building Renovation Diagnosis: A Case Study	Buildings
44	(Cattani et al., 2023)	Firms' Eco-innovation and Industry 4.0 Technologies in Urban and Rural Areas	Regional Studies
45	(Sjödin et al., 2023)	Artificial Intelligence Enabling Circular Business Model Innovation in Digital Servitization: Conceptualizing Dynamic Capabilities, AI Capacities, Business Models and Effects	Technological Forecasting and Social Change
46	(Zhang et al., 2023b)	Can Digital Transformation Drive Green Transformation in Manufacturing Companies? – Based on the Socio-Technical Systems Theory Perspective	Sustainability (Switzerland)
47	(Miao and Zhao, 2023)	Configurational Paths to the Green Transformation of Chinese Manufacturing Enterprises: A TOE Framework Based on the fsQCA and NCA Approaches	Scientific Reports
48	(van Erp and Rytter, 2023)	Design and Operations Framework for the Twin Transition of Manufacturing Systems	Advances in Production Engineering and Management
49	(Fan et al., 2023)	Digital Technology Application and Enterprise Competitiveness: The Mediating Role of ESG Performance and Green Technology Innovation	Environment, Development and Sustainability
50	(Chen et al., 2023)	Enabling the Twin Transitions: Digital Technologies Support Environmental Sustainability through Lean Principles	Sustainable Production and Consumption
51	(Wang et al., 2023)	Exploring the Effects of Manufacturing Servitization on Enterprise Energy Conservation and Emissions Reduction Moderated by Digital Transformation	Energy Economics
52	(Jurmu et al., 2023)	Exploring the Role of Federated Data Spaces in Implementing Twin Transition within Manufacturing Ecosystems	Sensors
53	(Peças et al., 2023)	Holistic Framework to Data-Driven Sustainability Assessment	Sustainability (Switzerland)
54	(Zhang et al., 2023a)	Impact of Digital Input on Enterprise Green Productivity: Micro Evidence from the Chinese Manufacturing Industry	Journal of Cleaner Production
55	(Laike and Ke, 2023)	Impact of Digital Transformation on Pollution Emissions of Manufacturing Enterprises in China: A Micro-level Analysis Based on Three-dimensional Panel Data	Resources Science
56	(Findik et al., 2023)	Industry 4.0 as an Enabler of Circular Economy Practices: Evidence from European SMEs	Journal of Cleaner Production
57	(Ogrean, 2023)	Interplays Between Artificial Intelligence and Sustainability in Business/ Management. A Bibliometric Analysis	Studies in Business and Economics
58	(Timmermans et al., 2023)	Introduction to the Special Issue on "The Twin (Digital and Green) Transition: Handling the Economic and Social Challenges"	Industry and Innovation
59	(Chatzistamoulou, 2023)	Is Digital Transformation the Deus ex Machina towards Sustainability Transition of the European SMEs?	Ecological Economics
60	(Kumar et al., 2023)	Progress in Sustainable Recycling and Circular Economy of Tungsten Carbide Hard Metal Scraps for Industry 5.0 and Onwards	Sustainability (Switzerland)
61	(Meyer et al., 2023)	Small and Medium-Sized Port Greening Initiatives as Trigger for a Servitisation Port Ecosystem	Environmental and Climate Technologies
62	(Kekkonen et al., 2023)	Stepping Towards the Green Transition: Challenges and Opportunities of Estonian Companies	Sustainability (Switzerland)
63	(Oloruntobi et al., 2023)	Sustainable Transition Towards Greener and Cleaner Seaborne Shipping Industry: Challenges and Opportunities	Cleaner Engineering and Technology
64	(Sassanelli et al., 2023)	The Disruptive Action of Industry 4.0 Technologies Cross-fertilizing Circular Economy throughout Society	ESRI
65	(Bianchini et al., 2023)	The Environmental Effects of the "Twin" Green and Digital Transition in European Regions	Environmental and Resource Economics
66	(Veugelers et al., 2023)	The Green and Digital Twin Transition: EU vs US Firms	Intereconomics
67	(Dabbous et al., 2023)	The Impact of Digitalization on Entrepreneurial Activity and Sustainable Competitiveness: A Panel Data Analysis	Technology in Society
68	(Spaltini et al., 2023)	The Role of Public-Private Partnership to Foster Twin Transition in Made in Italy: An Application Case	IEEE Transactions on Engineering Management
69	(Valentinov et al., 2023)	Toward a Digital Transformation of the Theory of the Firm: Emergence as Framework for Organizational Sustainability	Canadian Journal of Administrative Sciences
70	(Perossa et al., 2023)	Twin Transition Cosmetic Roadmapping Tool for Supporting Cosmetics Manufacturing	Cleaner Environmental Systems
71	(Paiho et al., 2023)	Twin Transition in the Built Environment – Policy Mechanisms, Technologies and Market Views from a Cold Climate Perspective	Sustainable Cities and Society
72	(Rehman et al., 2023)	Twin Transitions & Industry 4.0: Unpacking the Relationship between Digital and Green Factors to Determine Green Competitive Advantage	Technology in Society
73	(Lanfranchi et al., 2023)	Willingness to Adopt and Disseminate Projects Related to the "Twin Transition" on an Area. The Farmer's Perspective	Bulgarian Journal of Agricultural Science
74	(Pan et al., 2023)	Knowledge Mapping of Resilience and Human Rights in Supply Chains: A Roadmapping Taxonomy for Twin Green and Digital Transition Design	Frontiers in Environmental Science
75	(Rahnama et al., 2022)	Collaboration in Value Constellations for Sustainable Production: The Perspective of Small Technology Solution Providers	Sustainability (Switzerland)
76	(Korucuk et al., 2022)	Assessing Green Approaches and Digital Marketing Strategies for Twin Transition via Fermatean Fuzzy SWARA-COPRAS	Axioms
77	(Guang-lin and Tao, 2022)	How can Management ability Promote Green Technology Innovation of Manufacturing Enterprises? Evidence from China	Frontiers in Environmental Science
78	(Ruan et al., 2022)	Research on the Practical Path of Resource-Based Enterprises to Improve Environmental Efficiency in Digital Transformation	Sustainability (Switzerland)
79	(Ferreira et al., 2022)	The Interactions of Entrepreneurial Attitudes, Abilities, and Aspirations in the (Twin) Environmental and Digital Transitions? A Dynamic Panel Data Approach	Technology in Society
80	(Husain et al., 2022)	The Response of Green Energy and Technology Investment to Climate Policy Uncertainty: An Application of Twin Transitions Strategy	Technology in Society

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#	Authors	Title	Source title
81	(Ogrean and Herciu, 2021)	Romania's SMEs on the Way to EU's Twin Transition to Digitalization and Sustainability	Studies in Business and Economics
82	(Gerlitz and Meyer, 2021)	Small and Medium-Sized Ports in the TEN-T Network and Nexus of Europe's Twin Transition: The Way Towards Sustainable and Digital Port Service Ecosystems	Sustainability (Switzerland)
83	(Ortega-Gras et al., 2021)	Twin Transition through the Implementation of Industry 4.0 Technologies: Desk-research Analysis and Practical Use Cases in Europe	Sustainability (Switzerland)

Data availability

No data was used for the research described in the article.

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