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Research article

Navigating the twin transition through human capital: Insights from the fashion industry

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ABSTRACT

The twin transition toward sustainability and digitalization has attracted growing scholarly attention, yet limited empirical evidence explains how these dimensions are implemented and integrated within organizations. In particular, little is known about how sustainability, digital technologies, and human capital configurations interact and are integrated in practice. This study addresses this gap through a multiple case study of five companies in the fashion industry, based primarily on semi-structured interviews. The findings identify four recurring cross-case patterns. First, sustainability practices remain predominantly human-driven and largely predate digitalization, being embedded in design decisions, material sourcing, and relational supply chain coordination. Second, digital technologies are mainly adopted for compliance, monitoring, and reporting purposes, generating a persistent data–decision gap in which increasing data availability does not translate into improved managerial decision-making. Third, a systematic mismatch emerges between the current compliance-oriented role of digital systems and organizations' expectations of more integrative and strategic digital support. Fourth, the effectiveness of the twin transition depends less on the mere presence of digital or sustainability skills than on how competences are configured and integrated across functions. In this context, human capital performs a bridging and compensatory role, connecting fragmented systems and enabling cross-functional alignment. The study contributes theoretically by challenging techno-centric interpretations of digital transformation and conceptualizing the twin transition as an organizational capability-building process shaped by competence configuration rather than technology adoption alone. Accordingly, the proposed roadmap suggests that managers should prioritize integrative capability development and cross-functional coordination over further stand-alone investments in digital infrastructure.

1. Introduction

The twin green and digital transition is increasingly shaping the strategic agendas of manufacturing organizations, which are expected to pursue sustainability objectives while adapting to expanding digital infrastructures and data requirements (Schallmo and Jehle, 2025). In practice, however, this transition is often experienced as an ongoing and uncertain process rather than as a coherent transformation pathway. Sustainability initiatives, digital tools, and organizational routines frequently evolve at different paces, creating tensions that challenge firms' ability to translate strategic ambitions into everyday practices (Hammerschmidt et al., 2025; Trevisan et al., 2023).

In line with the emerging Industry 5.0 perspective, which emphasizes human-centric, resilient and sustainable forms of industrial transformation (European Commission, 2021), the twin transition unfolds through situated organizational processes rather than through the straightforward implementation of technologies or formal strategies. How sustainability-related activities are carried out and supported by digital means depends on a multitude of local decisions and adaptations shaped by organizational structures, resources, and existing practices (Dabbous et al., 2023; V. Fani et al., 2025). Consequently, understanding the twin transition requires attention to how organizations implement sustainability and digitalization in their daily operations, rather than focusing exclusively on technological adoption (Mäkitie et al., 2023).

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Human capital plays a central role in this context (Antonioli et al., 2025). Organizations increasingly rely on individuals and teams to interpret sustainability requirements, manage growing volumes of data, and coordinate across functional and organizational boundaries (Chen et al., 2023). Sustainability-related and digital competences are often unevenly distributed and mobilized through informal practices, placing substantial demands on organizational members to bridge different domains of expertise (Singh et al., 2025).

Despite growing interest in the twin transition, empirical insight into how sustainability-related practices and competences are implemented within firms remains limited. This study addresses this gap by examining how sustainability-related and digital practices and competences are configured and mobilized through a qualitative multiple case study in the fashion industry, a context characterized by strong sustainability pressures, fragmented supply chains and a high reliance on human judgment and coordination, (Colasante et al., 2025).

The remainder of the paper is structured as follows: Section 2 presents the theoretical background, Section 3 the research methodology, Section 4 the case study findings, Section 5 the discussion and finally Section 6 the conclusions.

2. Theoretical background

The twin transition is theorised in the literature as a systemic transformation in which digitalization and sustainability are intrinsically interdependent processes, rather than parallel or sequential change trajectories (Perossa et al., 2023; Spaltini et al., 2024). Digital technologies are conceptualised as enabling infrastructures that support efficiency, coordination, traceability, and data-driven decision-making across organizational and value-chain boundaries (Cascavilla et al., 2026), while sustainability provides the normative orientation that directs these technological capabilities towards long-term environmental and social objectives (Bianchi et al., 2024; Saari et al., 2024). Within this perspective, road mapping methodologies, maturity models, and structured assessment tools are framed as governance mechanisms that reduce complexity and uncertainty by aligning business priorities, sustainability goals, and technology investments (Saari et al., 2024). Accordingly, value creation in the twin transition is increasingly understood as the outcome of dynamic interactions among digital technologies, organizational practices, and institutional arrangements, rather than as the result of isolated technological adoption (Cascavilla et al., 2026). Within this line of reasoning, human capital is consistently positioned as a foundational enabling condition of the twin transition (Beducci et al., 2024; Hofmann Trevisan et al., 2024). The skills literature conceptualizes the transition towards circular and digitally enabled production systems as dependent on the availability, combination, and continuous renewal of heterogeneous competences (Carminati et al., 2025). These competences extend beyond purely technical knowledge to include digital capabilities, strategic-cognitive skills, and interpersonal and collaborative abilities that support coordination across functional and organizational boundaries (Acerbi et al., 2024; Wu, 2025). Rather than treating skills as static attributes, the literature frames them as dynamic and relational resources, developed through learning processes and embedded in organizational routines and practices (Braun et al., 2025; Powell et al., 2026). Several theoretical frameworks therefore propose multidimensional skill taxonomies for the circular economy and the twin transition, explicitly challenging the traditional hard-soft skills dichotomy (Vitti et al., 2025; Wu, 2025). Within these frameworks, integrative constructs such as systems thinking, circular mindset, and digital literacy are positioned as core elements of human capital that enable firms to navigate complexity and interdependencies across the value chain (Hofmann Trevisan et al., 2024; Vitti et al., 2025). Consequently, human capital emerges as a critical factor shaping firms' capacity to absorb digital technologies, operationalise sustainability strategies, and scale transformation initiatives across organizational units and industrial networks (Cascavilla et al., 2026; Rehman et al., 2023). From this perspective, the twin transition is closely intertwined with education and competence development systems, which are increasingly conceptualised as institutional infrastructures required to sustain long-term skill formation and continuous renewal (Panagiotopoulou et al., 2026; Trevisan et al., 2026). The literature highlights a persistent misalignment between the interdisciplinary and evolving skills required for the twin transition and the predominantly siloed structure of existing educational offerings (Trevisan et al., 2025). Current education and training programs tend to prioritize technical or domain-specific competences, underrepresenting digital, socio-behavioural, and resilience-oriented skills critical for circular and digital transformations (Vitti et al., 2025). In response, recent studies propose alternative educational models based on experiential and problem-based learning and hybrid environments such as learning factories, aimed at fostering integrative and transferable competences (Acerbi et al., 2026). These contributions frame education not merely as a supply-side mechanism, but as a co-evolutionary space where industrial needs, organizational practices, and public policy priorities interact (Beducci et al., 2023; Despeisse et al., 2024). Nevertheless, the literature acknowledges that the availability of competence frameworks does not automatically translate into effective skill deployment within firms, leaving open questions on how competences are internalised, recombined, and sustained in organizational contexts (Alfieri et al., 2025; Braun et al., 2025).

Finally, the twin transition is increasingly analysed through the lens of just transition, which introduces a normative and socio-economic dimension into the debate (Multani et al., 2025). This literature frames the green and digital transitions as processes that reshape labour demand, occupational profiles, and skill requirements, often generating uneven distributional effects across worker groups (Bianchi et al., 2024). While some circular strategies may increase labour intensity, they may also disadvantage low-skilled workers or exacerbate skill polarisation if not supported by targeted upskilling and reskilling initiatives (Sassanelli et al., 2025). Within this perspective, human capital is understood not only as a productive asset but also as a policy-relevant construct embedded in education systems, labour market regulation, and social protection (Carminati et al., 2025). The just transition framework thus reinforces the need to integrate technological change, competence development, and social equity within a unified analytical approach (Hassan et al., 2025).

Despite the growing conceptualization of the twin transition as a socio-technical phenomenon, existing studies offer limited insight into how human capital translates into organizational capabilities that sustain this transformation.

To empirically substantiate the identified research gap, a bibliographic search was conducted in February 2026, using Scopus for its reliability and broad coverage of relevant publications within these fields (Ren et al., 2019).

These results, summarized in Table 1 below, reinforce the claim that, despite growing conceptualization, the intersection of these dimensions remains underexplored at the organizational level.

The search identified 409 documents referring to the general "twin transition." Refining the query to include "sustainability" and "digital*" reduced the results to 196 publications. However, further restricting the

Table 1
Structured Scopus search results.

Research Query	Number of contributions
TITLE-ABS-KEY ("twin transition")	409
TITLE-ABS-KEY ("twin transition" AND "sustainability" AND "digital*")	196
TITLE-ABS-KEY ("twin transition" AND "sustainability" AND "digital*" AND "human*")	24
TITLE-ABS-KEY (("twin transition") AND ("case stud*" OR "empirical*"))	99

search to include competence-related terms ("human*") reduced the number to only 24 documents. Additionally, combining "twin transition" with empirical or case study-related terms yielded 99 publications, suggesting that although the concept is increasingly discussed, relatively few studies explicitly address the organizational integration of sustainability, digitalization, and human capital through empirically grounded research.

3. Methodology

Considering the limited empirical evidence on how organizations are developing human capital to address the twin transition, this study adopts a qualitative and exploratory research design. In line with Yin (2018), qualitative case-based research is well suited to address "how" questions and investigate complex phenomena that are still evolving in practice. As this study aims at theory building rather than theory testing, a multiple case study approach enables an in-depth understanding of organizational processes and practices while supporting the identification of cross-case patterns and critical dimensions (Eisenhardt, 1989). In this study, human capital is operationalized as the set of competences that enable organizations to implement and integrate sustainability and digital practices. Consistent with recent integrative skill frameworks (Carminati et al., 2025; Hofmann Trevisan et al., 2024), the study considers both hard and soft skills. Hard skills include technical and digital competences related to data management, traceability, and regulatory compliance, while soft skills encompass sustainability-related knowledge, cross-functional coordination, systems thinking, and boundary-spanning capabilities. Human capital is therefore examined through its practical manifestation in organizational processes rather than as an abstract skill construct.

3.1. Case selection

Cases were selected following a convenience sampling strategy with a strong theoretical orientation (Voss et al., 2002), based on their accessibility and their theoretical relevance to the research phenomenon. The study focused on organizations actively engaged in sustainability initiatives while simultaneously facing increasing pressure to adopt digital technologies to support them. This enabled the investigation of contexts in which the challenges of integrating green and digital dimensions, along with their human capital implications, were already salient. The empirical setting of the study is the fashion industry, which represents a particularly suitable context for examining the twin transition. First, many production, design, and supply chain activities remain partially manual and creativity-driven, which constrains the extent to which digital technologies can be fully standardized or automated (Virginia Fani et al., 2025). Second, sustainability-related data are typically fragmented across multiple actors and systems, increasing the complexity of data collection, integration, and interpretation (Acerbi et al., 2025). These characteristics amplify the role of human capital, as the effectiveness of digital solutions largely depends on individuals' ability to make sense of data and translate it into actionable decisions.

Five companies operating in the fashion sector were selected to ensure variation in organizational size and market positioning while maintaining a shared industrial and institutional context, in line with methodological guidelines on case study research (Rowley, 2002).

The fashion industry, however, is not homogeneous. Building on established distinctions in operations and supply chain research, it is possible to differentiate between fast fashion and slow fashion configurations, which diverge in business models, product life cycles, supply chain responsiveness, and competitive priorities (Sellitto et al., 2022).

Within this framework, the sample includes one fast fashion configuration and four slow fashion configurations. The fast fashion case operates with shorter product cycles and rapid collection renewal, whereas the remaining companies follow longer planning horizons and more stable assortment logics. This distinction is acknowledged to enhance conceptual clarity and avoid sectoral oversimplification. However, the purpose of this study is not to compare fast and slow fashion models. Rather, the unit of analysis remains the organization, and the focus lies on how sustainability, digitalization, and human capital are internally integrated within firms operating under different competitive configurations. The fast-slow distinction therefore serves as contextual framing, not as a comparative analytical dimension.

Companies were contacted via email and informed about the study objectives and interview protocol; participation was voluntary and confidentiality was guaranteed (Creswell and Poth, 2016; Fani et al., 2024). To preserve anonymity, cases are referred to as Company A to Company E, with company size classified according to the European Union's definition of firm size, as reported in Table 2 (Belhadi et al., 2020).

The unit of analysis is the organization, with particular attention to managerial perspectives related to sustainability, digitalization, and strategic decision-making. While the twin transition often involves broader supply networks and ecosystems, this study deliberately focuses on internal organizational dynamics and human capital development processes, which remain underexplored in existing empirical research.

3.2. Data collection

Data collection was conducted between May and September 2025. Semi-structured interviews were adopted as the primary data collection method. This approach allows researchers to gather in-depth empirical evidence while maintaining sufficient flexibility to explore emerging themes (Eisenhardt and Graebner, 2007).

In particular, interviews were conducted with sustainability managers, strategy leads, and IT managers, depending on the organizational structure of each case. These roles were considered especially relevant as they are closely involved in interpreting sustainability requirements, interacting with digital tools and data, and translating external pressures, such as regulatory demands and market expectations, into internal organizational practices.

Interviews were conducted through video conferencing, a choice motivated by logistical considerations and consistent with established qualitative research practices (Creswell and Poth, 2016). Each interview lasted an average of 45 min. With the participants' consent, each interview was audio-recorded and subsequently transcribed verbatim to ensure accuracy.

An interview protocol was developed (Yin, 2018) to guide the semi-structured interviews and support the exploration of sustainability initiatives, digital technologies (both current and prospective), competence-related challenges, and integration mechanisms within the context of the twin transition. The full set of guiding questions is reported in Appendix A (see Table 1A) to enhance transparency and replicability. While all respondents were asked the same core questions, the emphasis and depth of discussion varied depending on the

Table 2
Overview of the case companies.

Company ID	Company size	Sub-industry	Fashion configuration	Interviewed role (s)
A	Large	Luxury leather goods & accessories	Slow	Sustainability Manager
B	Large	Mass-market apparel retail	Fast	Strategy Lead
C	Large	Luxury shoes & accessories	Slow	IT Manager; Sustainability Manager
D	Small	Contemporary apparel	Slow	Sustainability Manager
E	Medium	Outerwear & performance apparel	Slow	Sustainability Manager

interviewee's role and expertise (Kvale and Brinkmann, 2009; Vellesalu et al., 2023). To enhance data credibility, interviewees were provided with a structured summary of the main insights and invited to validate their accuracy, thereby reducing interpretative bias. Data triangulation was used to strengthen robustness by complementing interviews with secondary sources, including corporate websites, press releases, and technology partnership announcements, as well as follow-up email exchanges when needed (Jick, 1979; Rossini et al., 2021).

3.3. Data analysis

Data analysis followed an iterative and abductive process articulated in two stages: within-case and cross-case analysis (Tortorella et al., 2021; Yin, 2018), consistent with exploratory theory-building research. First, each case was analysed individually through the development of a case narrative based on interview transcripts, field notes, and secondary data. Interview material was systematically coded and reduced (Brarda et al., 2026; Miles, 1994) by grouping relevant excerpts around key analytical dimensions derived from both the research objectives and emerging empirical insights, including sustainability practices, digital support, competence gaps, hybrid skills, and organizational barriers. Coding was conducted following the guidelines suggested by Yin (2018). Following an inductive coding logic, first-order concepts were progressively aggregated into second-order themes and aggregate dimensions (Braun and Clarke, 2006; O'Connor and Joffe, 2020). Table 3 provides an illustrative example of the coding process across cases, showing how data-driven concepts were progressively aggregated into higher-level analytical dimensions.

Second, a cross-case analysis was conducted to identify recurring patterns and contrasts across the five cases (Yin, 2018). Cases were compared along shared analytical dimensions, with particular attention to how sustainability and digital initiatives were integrated and how human capital configurations shaped capability development. Comparative tables and matrices were used as data displays to support pattern identification and ensure traceability to the empirical material (Miles, 1994). This process enabled the abstraction of cross-case insights that form the basis for the findings and discussion, without aiming at statistical generalization.

4. Key findings

4.1. Within-case analysis

4.1.1. Company A

Company A operates in the fashion accessories sector and shows a long-standing commitment to sustainability that predates digitalization. Sustainability practices are deeply embedded in product characteristics, material selection, and supplier relationships, relying heavily on manual coordination and tacit knowledge across functions and external partners. As a result, sustainability work is perceived as intrinsically complex and strongly dependent on human judgment rather than standardized or automated processes. Digital technologies play a supportive but limited role, mainly oriented toward data collection, reporting, and compliance in response to growing regulatory and transparency requirements. This description is consistent with information disclosed through technology partnership announcements referring to blockchain-based traceability solutions adopted to enhance transparency and reporting, reinforcing the primarily compliance-oriented role of digital tools described by interviewees. Interviewees described a fragmented digital landscape characterized by multiple tools, spreadsheets, and parallel systems. Although sustainability-related data availability has increased, this has not translated into improved decision-making, revealing a gap between data generation and usability. From a human capital perspective, sustainability expertise is well established, while digital competences are unevenly distributed and concentrated in specific roles. This configuration creates a strong reliance on a limited number of key actors who informally bridge sustainability, digital, and business domains. Consequently, competence development largely occurs through experience-based learning rather than structured training initiatives. These dynamics generate organizational tensions, as strong sustainability ambitions coexist with fragmented digital infrastructures. The parallel evolution of sustainability and digital initiatives limits systematic skill development and constrains the organization's ability to move beyond incremental improvements in leveraging digital technologies for sustainability goals.

Table 3
Illustrative example of the coding process across cases.

Company ID	1st-order concepts	2nd-order themes	Aggregate dimensions
A	Sustainability expertise concentrated in specific roles	Uneven distribution of competences	Human capital configuration
B	Sustainability driven by regulation and reputation	Externally driven sustainability strategy	Sustainability practices
C	Lack of integrated data governance	Governance gap limiting technology use	Organizational barriers
D	Collaboration with vocational schools and ITS	External partnerships for skill development	Human capital development
E	Digital Product Passport (DPP) as main digital tool	Selective digital adoption	Digital support to sustainability

4.1.2. Company B

Company B operates in the fashion sector with a focus on apparel and accessories and faces sustainability challenges driven by scale, cost pressure, and supply chain complexity. Sustainability initiatives are largely shaped by regulatory requirements, stakeholder expectations, and reputational concerns and are embedded in standardized procedures and supplier management practices. Despite this formalization, sustainability work remains highly complex and dependent on coordination across a geographically dispersed network of internal and external actors. Digital technologies play a central role in supporting sustainability activities, particularly for data collection, monitoring, and reporting across the supply chain. Interviewees reported extensive use of digital tools to track environmental and social indicators and ensure regulatory compliance. This configuration is also reflected in publicly communicated technology collaborations focused on supplier traceability and monitoring systems, which emphasize compliance, data aggregation, and supply chain visibility. However, digital systems are perceived as fragmented and primarily compliance-oriented, resulting in a persistent gap between data availability and actionable sustainability decision-making. From a human capital perspective, digital and sustainability competences are unevenly distributed and weakly integrated. Skills tend to reside in separate teams, limiting cross-functional understanding and placing strong reliance on informal boundary-spanning individuals. Training activities are largely reactive and role-specific, offering limited support for the development of integrated competences.

As a result, sustainability and digital initiatives evolve in parallel rather than in a coordinated manner. This configuration constrains systematic human capital development and limits the organization's ability to move beyond a compliance-driven approach toward more transformative uses of digital technologies for sustainability.

4.1.3. Company C

Company C operates in the fashion sector with a focus on accessories and faces strong sustainability and compliance demands linked to the need for visibility across a complex, multi-tier supply chain. Sustainability work remains highly labour-intensive, relying on manual data

collection and individual expertise to retrieve information from upstream actors with limited digital readiness. As a result, sustainability practices are only partially standardized and strongly dependent on human coordination and interpretative work. Digital technologies are considered essential to manage traceability, data collection, and impact measurement. Company C has adopted multiple external digital tools, largely in response to regulatory requirements. While these systems support data aggregation and disclosure, they remain fragmented and poorly integrated, limiting their ability to provide a comprehensive and real-time view of sustainability performance. Advanced analytics and AI applications are being explored through pilot initiatives but have not yet been operationalized at scale.

From a human capital perspective, sustainability expertise is well established, whereas digital and data-related competences are unevenly distributed. Integration across sustainability, IT, and compliance domains relies on a limited number of key individuals, with learning occurring mainly through problem-solving and on-the-job experience. The lack of integrated data governance and structured capability development reinforces organizational silos and constrains the effective translation of digital potential into sustained organizational change.

4.1.4. Company D

Company D operates in the fashion sector with a focus on apparel manufacturing and is characterized by strong territorial embeddedness and a long-standing commitment to local production. Sustainability practices are deeply rooted in the company's identity and supply chain structure, relying on a short, predominantly local network and values-driven initiatives such as renewable energy self-production, certified materials, and sustainable packaging. These practices largely predate digitalization and depend on close relationships with small-scale suppliers and artisanal shops. Digital technologies are introduced incrementally to support and formalize existing sustainability practices rather than to transform them. The company has piloted solutions such as the DPP, optical quality control systems, and waste-reduction software, reflecting a cautious approach shaped by limited resources and the low digital readiness of upstream partners. These initiatives are also visible on the company's corporate website, which highlights digital product passport experimentation and traceability-oriented digital tools as part of its sustainability communication. While digital tools are recognized as enablers of traceability and transparency, their implementation remains labour-intensive and fragmented. From a human capital perspective, sustainability-related competences are relatively strong and supported by collaborations with vocational schools and technical institutes, whereas digital skills are unevenly distributed and primarily developed through on-the-job learning. The company's small size facilitates flexibility and role hybridity, enabling cross-functional learning, but the absence of formalized roles and structured training pathways limits the scalability of capability development. As a result, Company D's commitment to the twin transition is constrained by structural limitations typical of small manufacturing firms, particularly in systematizing and sustaining human capital development.

4.1.5. Company E

Company E operates in the fashion sector with a focus on apparel and exhibits a strong sustainability orientation embedded in everyday organizational practices. Sustainability activities are largely managed through manual processes and intensive coordination with suppliers, with data collected via emails and documents and consolidated in spreadsheets. This results in sustainability work that remains highly human-intensive and dependent on continuous interaction rather than on automated systems. Digital technologies play a selective role in supporting sustainability. The main exception is the adoption of a DPP, implemented through an external partner to communicate sustainability information to customers. This account aligns with the company's corporate website, which presents the digital product passport as a tool for communicating product-level sustainability information to consumers. Beyond this use case, digital solutions for internal data integration and analysis remain limited, as available platforms are perceived mainly as repositories for manually collected data rather than as tools for generating analytical insight. From a human capital perspective, sustainability competences are well developed and continuously updated through external networks, working groups, and specialized consultants, enabling alignment with evolving regulatory requirements. Digital competences are not perceived as a major gap, supported by a relatively young and digitally fluent workforce that shows agility in adopting new tools. However, human capital development remains largely informal and practice-based. The absence of integrated digital infrastructures constrains the effective use of existing skills, leaving the organization focused on managing fragmented data flows rather than advancing toward more systematic sustainability analysis and decision support.

4.2. Cross-case analysis

Building on the within-case, this section presents a cross-case analysis aimed at identifying recurring patterns that cut across the five cases. Table 4 synthesizes the key analytical dimensions emerging from the empirical material and serves as a reference point for the cross-case analysis.

Drawing on this synthesis, the following subsections highlight a set of transversal patterns that explain how sustainability practices, digital technologies, and human capital configurations interact in different organizational contexts. Together, these patterns provide insight into the structural conditions and organizational mechanisms that enable or constrain the development of capabilities for the twin transition. Fig. 1 provides an integrative overview of the cross-case patterns emerging from the analysis. It highlights the human-driven and pre-digital nature of sustainability practices, the compliance-oriented role of current digital technologies and the resulting data-decision gap, as well as the growing mismatch between current and expected digital roles. The figure also shows how human capital configurations address these tensions by bridging fragmented systems and practices.

4.2.1. Sustainability as a human-driven and pre-digital practice

Across the five cases, sustainability practices consistently emerge as predominantly human-driven and embedded in organizational routines that largely predate the adoption of digital technologies. Sustainability is primarily grounded in product design choices, material selection, supplier relationships, and localized production logics, rather than being enabled by digital systems. Even in organizations with relatively high levels of digital maturity, sustainability activities rely heavily on human judgment, tacit knowledge, and continuous coordination across internal functions and external partners.

This pattern is particularly evident where sustainability is closely tied to product identity and value creation. In Companies A and D, sustainability is described as integral to the organization's way of operating, shaped by long-standing decisions related to materials, craftsmanship, and supply chain structure. In these contexts, digital tools play a secondary role, mainly supporting documentation and reporting rather than driving sustainability outcomes. As one interviewee observed, sustainability "starts from materials and design choices, not from a system or a tool" (Company A).

In larger and more complex organizations such as Companies B and C, sustainability practices remain highly human-intensive despite the presence of more advanced digital systems. The scale and opacity of global supply chains increase the need for manual coordination and interpretative work to collect, validate, and contextualize sustainability-related information, particularly in upstream tiers with limited digitalization. As noted by an interviewee from Company C, "a lot of sustainability data still needs to be collected manually from suppliers."

Company E further reinforces this pattern from a different organizational configuration. Despite a strong sustainability orientation and a

Table 4
Cross-case overview of key analytical dimensions.

Dimension	Company A	Company B	Company C	Company D	Company E
Nature of sustainability practices	Embedded in materials and product design; highly tacit and relationship-based	Scale-driven and externally pressured; strong supply-chain complexity	Labour-intensive and compliance-driven; limited upstream visibility	Values-driven and locally embedded; short and territorial supply chain	Strongly embedded but largely managed through manual processes
Role of digital technologies (Now)	Fragmented systems mainly supporting reporting and compliance	Extensive monitoring and reporting across the supply chain	Essential for traceability and compliance, but poorly integrated	Incremental digital support to formalize existing practices	Selective use, mainly for external transparency (e.g., DPP)
Expected role of digital technologies (Future)	End-to-end data integration and decision support for sustainability	Advanced analytics for emission accuracy and hotspot identification	Automation of data collection and real-time compliance monitoring	Full traceability and monitoring to support certifications and DPP	Interoperable platforms enabling internal analysis and supplier integration
Human capital configuration	Strong sustainability expertise; digital skills uneven and concentrated	Functional silos with informal boundary-spanning roles	Hybrid competences concentrated in few key actors	Sustainability skills strong; digital skills mainly learned on the job	Sustainability and digital skills relatively aligned
Main organizational barriers	Lack of system integration; high manual workload	Organizational complexity and legacy systems	Siloed functions and lack of data governance	Resource constraints and limited scalability of training	Limited availability of truly enabling digital solutions

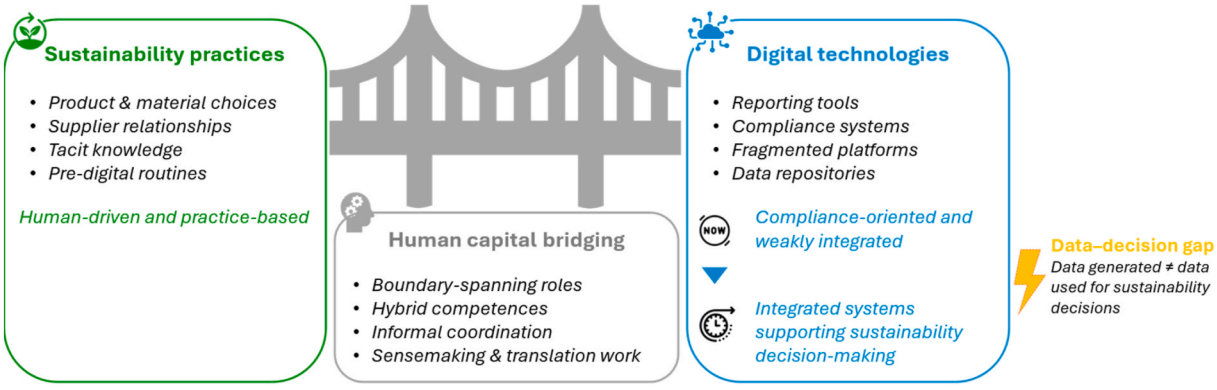

Fig. 1. Synthesis of cross-case patterns.

digitally fluent workforce, sustainability activities remain largely managed through manual processes and intensive coordination with suppliers, with data consolidated in spreadsheets and informal tools. This indicates that even where digital competences are present, sustainability work continues to rely primarily on human effort in the absence of integrated digital infrastructures.

Overall, this cross-case pattern challenges techno-centric narratives that frame digitalization as the primary driver of sustainability transformation. Instead, the findings show that sustainability practices are fundamentally organizational and relational phenomena, grounded in human capabilities and context-specific routines. Digital technologies are layered onto these practices at a later stage, mainly to formalize, document, or communicate sustainability efforts, rather than to originate them. This human-driven and pre-digital nature of sustainability constitutes a foundational condition shaping how organizations subsequently approach the digital dimension of the twin transition.

4.2.2. Digitalization for compliance and the data-decision gap

Across the five cases, digital technologies are predominantly adopted to support compliance, monitoring, and reporting requirements, rather than to enable strategic sustainability decision-making. The current role of digital technologies is largely associated with data collection, traceability, and disclosure, reflecting increasing regulatory pressure and demands for transparency from external stakeholders. While the extent of digitalization varies across organizations, a common pattern emerges in which digital systems generate growing volumes of sustainability-related data without a corresponding increase in their use for managerial sensemaking and action.

This compliance-oriented logic is particularly evident in Companies B and C, where digital tools support the monitoring of complex and multi-tier supply chains and the aggregation of environmental and social indicators. Despite this extensive data infrastructure, systems remain fragmented and weakly integrated, with sustainability data primarily serving reporting purposes rather than informing operational or strategic decisions. As one interviewee from Company B noted, “we track a lot of data across suppliers, but systems are mainly designed for compliance.”

A similar dynamic is observed in Company A, albeit at a different scale. Despite the presence of multiple digital systems supporting reporting and vendor management, interviewees emphasized the difficulty of transforming data into actionable insights. The reliance on spreadsheets and parallel data repositories requires extensive manual consolidation and interpretation. As noted by a respondent, “having data doesn't mean you can actually use it to take decisions” (Company A).

Even in smaller and more sustainability-oriented organizations, such as Companies D and E, digital technologies are primarily used to formalize and communicate sustainability practices rather than to guide internal decisions. Tools such as the DPP support transparency toward consumers and certification bodies, but do not substantially alter how sustainability is managed internally. As an interviewee from Company E observed, many platforms “just store data without adding real value”.

Taken together, these findings reveal a pervasive data-decision gap across cases. Digital technologies succeed in producing and organizing sustainability-related information, yet they fall short of supporting interpretation, prioritization, and action. This gap is not primarily attributable to the absence of data or tools, but to the way digitalization is framed and implemented, namely, as a response to compliance requirements rather than as a means to enhance organizational learning and decision-making. This pattern sets the stage for the growing tension

between current digital practices and the more ambitious expectations associated with the future role of digital technologies in the twin transition.

4.2.3. The growing mismatch between current and expected roles of digital technologies

The cross-case analysis reveals a systematic mismatch between the current role of digital technologies in supporting sustainability and the role organizations expect them to play in the future. While present digital solutions are largely fragmented and compliance-oriented, future expectations consistently point toward integrated systems capable of supporting sensemaking, decision-making, and strategic prioritization in sustainability management. This discrepancy highlights the transitional and incomplete nature of the digital dimension of the twin transition.

Interviewees articulated expectations for digital technologies that go beyond data collection and reporting. Organizations envision digital infrastructures enabling end-to-end data integration across functions and supply chain actors, advanced analytics to identify environmental hotspots, and real-time monitoring to support proactive sustainability decisions. Respondents from Companies A and B emphasized the need for tools that translate sustainability data into insights meaningful for business strategy. As one interviewee noted, future systems should "help interpret data and support decisions, not just collect information" (Company A). These expectations are consistent with the literature conceptualizing digitalization as an enabling infrastructure for coordination, traceability, and data-driven decision-making across organizational boundaries (Cascavilla et al., 2026), yet our findings indicate that such integrative potential remains only partially realised in practice.

This aspirational view contrasts sharply with the current technological landscape. In Companies A, B, and C, existing systems are characterized by limited interoperability, reliance on parallel data repositories, and heavy dependence on manual consolidation. Even where advanced technologies such as artificial intelligence are explored, as in Company C, their application remains confined to pilot initiatives, constrained by data quality issues and the absence of shared governance frameworks. As an interviewee from Company C explained, "outputs still require a lot of verification before they can be used".

This suggests that the challenge is not technological scarcity, but the absence of robust organizational routines and integrative competences capable of embedding digital outputs into strategic decision processes.

Smaller organizations, such as Companies D and E, express similar expectations from different starting points. In these cases, digitalization is expected to replace labour-intensive manual processes and enable more systematic sustainability analysis, yet progress is limited by the lack of scalable and interoperable solutions. As highlighted by a respondent from Company E, many platforms are perceived as "containers for data that we already collect manually," rather than as tools capable of transforming sustainability work. Across cases, increasing data availability does not automatically translate into enhanced decision quality, revealing the persistence of a data-decision gap rooted in competence configuration rather than in technological absence.

Overall, this pattern shows that organizations are caught between a present state in which digital technologies primarily serve administrative and compliance functions and a future-oriented vision in which digitalization is expected to act as a cognitive and integrative enabler of sustainability. The growing gap between these two roles generates organizational tension and uncertainty, as investments in digital tools do not yet align with the capabilities organizations seek to develop. This mismatch constitutes a critical condition shaping the evolution of the twin transition and underscores the importance of organizational and human factors in bridging the distance between current practices and future aspirations. This tension can be interpreted as a capability formation bottleneck: digital systems evolve, but the multidimensional competences required to interpret, recombine, and strategically leverage sustainability data, such as digital literacy, systems thinking, and cross-functional coordination (Hofmann Trevisan et al., 2024), remain unevenly configured. By empirically uncovering this structural mismatch, the study advances existing conceptualisations of the twin transition as a socio-technical co-evolution (Spaltini et al., 2024) and responds to the identified research gap concerning how human capital translates into organizational capabilities sustaining digital-sustainability integration.

4.2.4. Human capital configurations as bridging role in the twin transition

The cross-case analysis indicates that human capital configurations play a critical bridging role in shaping how organizations navigate the twin transition. The effectiveness of sustainability-oriented digitalization does not primarily depend on the availability of technologies, but on how sustainability-related knowledge and digital competences are distributed, coordinated, and embedded within organizational structures. Across cases, skills and expertise are present, yet unevenly configured, resulting in significant variation in organizations' ability to translate digital investments into meaningful sustainability outcomes.

In several cases, sustainability expertise is well established but weakly connected to digital and analytical capabilities. In Companies A and C, sustainability knowledge is concentrated in specific functions or individuals, while digital skills related to data integration, governance, and interpretation are unevenly distributed. This configuration creates a strong reliance on informal boundary-spanning roles embodied by a limited number of key actors who translate sustainability data into business-relevant insights. As one interviewee observed, "only a few people can really connect sustainability, IT, and compliance" (Company C).

A similar reliance on informal integration emerges in Company B, where organizational scale and complexity reinforce functional silos between sustainability, digital, and commercial teams. Although specialized skills exist within each domain, their separation constrains cross-functional learning and places the burden of integration on informal roles that lack formal recognition. As noted by an interviewee, some individuals end up "translating between sustainability and business without this being a formal role" (Company B).

Smaller organizations display different but equally consequential configurations. In Company D, sustainability-related skills are relatively strong and supported by external collaborations, while digital competences are largely developed through on-the-job learning. The firm's small size enables flexibility and role hybridity, but the absence of formalized roles and structured training limits the scalability of capability development. In Company E, sustainability and digital skills are perceived as relatively aligned, yet the lack of integrated digital infrastructures constrains their effective deployment, with efforts focused on managing fragmented data flows rather than higher-level analysis and decision support.

Taken together, these findings suggest that the twin transition is shaped less by the presence or absence of specific skills than by their organizational configuration. Across cases, strong sustainability ambitions coexist with fragmented or compliance-oriented digital systems, placing increasing demands on human capital to compensate for technological and organizational shortcomings. Learning and capability development therefore occur largely through informal, experience-based processes rather than systematic training initiatives. This reliance on individual effort limits the scalability of integrated competences and contributes to the persistence of the gaps identified in the previous patterns. Consequently, human capital emerges simultaneously as a central lever and a structural constraint in enabling the transition toward more integrated, knowledge-driven approaches to the twin green and digital transition.

5. Discussion

The cross-case patterns provide several implications for theory and practice on human capital development in the twin green and digital

transition. From a theoretical perspective, the findings nuance technology-centric accounts by showing that sustainability practices remain predominantly human-driven and embedded in routines that often predate digitalization, while digital technologies are largely deployed for monitoring, reporting, and compliance. The resulting data-decision gap indicates that the twin transition is constrained less by digital tool availability than by the organizational capacity to align sustainability practices, digital infrastructures, and decision processes, reinforcing socio-technical perspectives on the co-evolutionary nature of the transition.

This interpretation is consistent with studies that conceptualize the twin transition as a systemic and socio-technical transformation rather than as the simple juxtaposition of green and digital initiatives (Perossa et al., 2023; Spaltini et al., 2024). It also complements work emphasizing that digital technologies can support sustainability through coordination, traceability, and data management (Cascavilla et al., 2026; Chen et al., 2023), by showing that, in practice, these enabling functions often remain confined to administrative and compliance-oriented uses rather than being translated into integrative decision support. In this sense, the findings also extend prior work on digitalization and sustainability transitions (Dabbous et al., 2023; Mäkitie et al., 2023) by highlighting that the main bottleneck lies not only in technology adoption, but in the organizational conditions required to embed digital outputs into everyday sustainability management.

An additional layer of interpretation concerns the role of firm size in shaping how the data-decision gap manifests. While the gap emerges across all cases, its underlying drivers differ between larger and smaller organizations. In larger firms, the gap appears to be primarily linked to organizational complexity, legacy systems, and functional silos that fragment data flows and hinder cross-functional integration. The coexistence of multiple digital platforms and specialized teams generates abundant data, yet limits its strategic usability. In smaller firms, by contrast, the gap is less associated with structural fragmentation and more with resource constraints, limited scalability of digital infrastructures, and the absence of formalized governance mechanisms. In these contexts, digitalization remains incremental and heavily dependent on individual effort. Firm size, therefore, does not determine whether the data-decision gap exists, but rather shapes the organizational mechanisms through which it is produced and sustained. This result adds nuance to extant literature on organizational transformation under the twin transition, which has recognized the importance of context and structural conditions (Schallmo and Jehle, 2025), but has provided limited empirical explanation of how similar integration problems may arise through different mechanisms depending on organizational scale.

A second theoretical implication concerns the role of human capital. Rather than focusing on skills as static attributes or "missing" competences, the findings show that transformation depends on how sustainability-related and digital competences are configured and mobilized across organizational structures. Across cases, competence integration relies heavily on informal boundary-spanning roles concentrated in a limited number of actors, highlighting human capital as an enabling and compensatory mechanism that enables progress while generating scalability constraints when integration depends on individuals rather than on routinized capabilities.

This interpretation is consistent with recent literature that frames human capital as a foundational enabling condition of the twin transition (Hofmann Trevisan et al., 2024) and with studies emphasizing the importance of integrative competences such as systems thinking, digital literacy, and cross-functional collaboration (Wu, 2025). At the same time, our findings extend this literature by showing that the critical issue is not only the presence of such competences, but how they are organizationally distributed, connected, and mobilized in practice.

From a practical perspective, the findings indicate that investments in digital solutions should be complemented by deliberate efforts to design scalable competence configurations. The results provide actionable insights for human capital development, training, and upskilling initiatives supporting the twin transition. Rather than focusing on isolated technical or sustainability-related competences, training should prioritize integrative learning objectives fostering systems thinking, data interpretation, and cross-domain sensemaking, as key challenges stem from difficulties in connecting sustainability knowledge, digital skills, and decision-making across functional boundaries.

The findings further highlight the relevance of cross-functional and practice-based learning formats. The reliance on experiential and problem-based learning suggests that competence development largely occurs through informal mechanisms. Translating these dynamics into scalable organizational capabilities requires learning environments that integrate sustainability, digital, and business functions around shared challenges, making cross-functional projects, rotational roles, and collaborative problem-based training more effective than traditional classroom-based or function-specific courses.

Finally, the results challenge the effectiveness of training programs focused predominantly on technical digital skills detached from organizational context. While digital literacy remains important, digital competences alone do not ensure effective sustainability decision-making. Training initiatives that neglect data governance, organizational routines, and interfunctional coordination risk reinforcing compliance-oriented uses of digital technologies. Overall, these implications suggest that supporting the twin green and digital transition requires a shift from skill acquisition to capability building, aligned with the human-centric principles emphasized in the Industry 5.0 agenda (European Commission, 2021). Taken together, advancing the twin transition in fashion companies therefore requires coordinated adjustments across four managerial levers: organizational design, decision-making processes, HR policies and role design, and training and strategic investment governance. Rather than introducing entirely new initiatives, firms need to formalize cross-functional governance mechanisms, embed sustainability data into strategic decision cycles, institutionalize hybrid roles to reduce dependence on informal boundary-spanning actors, and align digital investments with structured integrative capability-building strategies. Table 5 synthesizes these managerial shifts and clarifies how the empirical findings translate into actionable organizational change.

Building on Table 5, Fig. 2 presents a capability-oriented roadmap

Table 5
Managerial implications of the study for the fashion industry.

Empirical Finding	Organizational Issue Identified	What Should Change	Managerial Lever
Sustainability remains predominantly human-driven	Fragmented integration between sustainability and core business functions	Formalize cross-functional governance structures integrating sustainability, digital, and strategic units	Organizational design
Persistent data-decision gap	Digitalization limited to compliance and reporting functions	Embed sustainability data into strategic planning and performance management cycles	Decision-making processes
Informal boundary-spanning roles	Dependence on individual initiative limits scalability	Institutionalize hybrid roles and clarify cross-functional accountability	HR policies & role design
Competence and technology misalignment	Siloed skill development and uncoordinated digital investments	Align digital investments with structured integrative capability-building strategies	Training & strategic investment governance

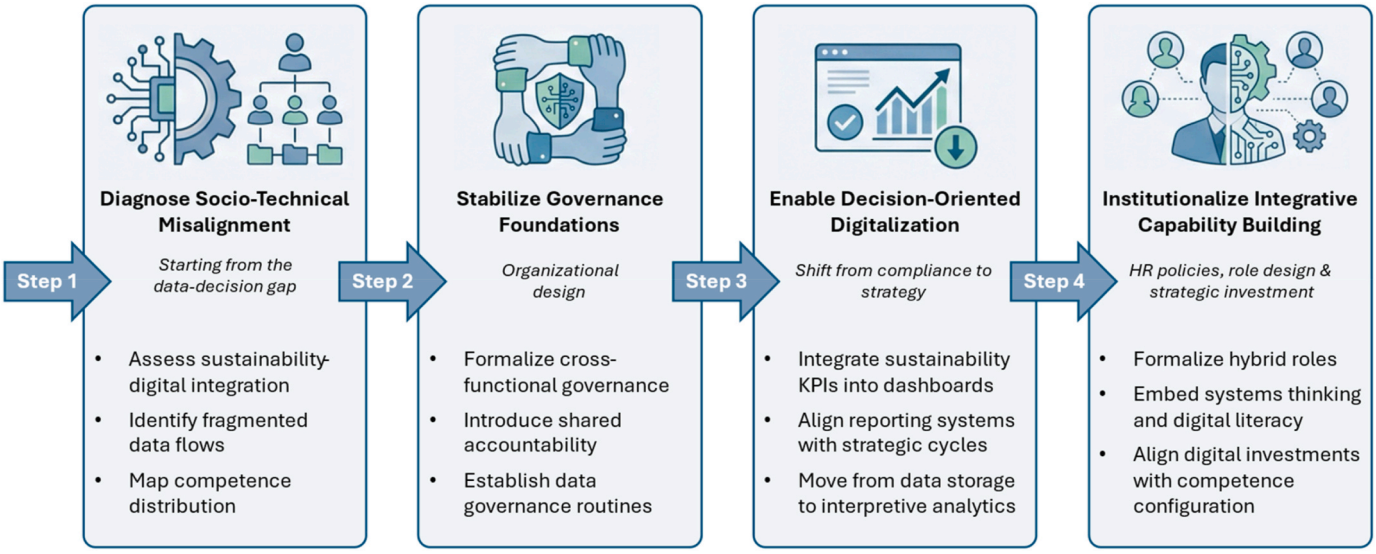

Fig. 2. A roadmap for operationalizing the twin transition in fashion firms.

that operationalizes the study's insights into a sequence of interconnected actions. The roadmap illustrates how organizations can progressively move from diagnosing socio-technical misalignment to institutionalizing integrative capability building, thereby reducing the data-decision gap and strengthening sustainable digital transformation.

5.1. Contributions to knowledge and practice

Building on the findings and the discussion above, this study contributes to knowledge in three main ways. First, it conceptualizes the twin transition as an organizational capability-building process rather than as the outcome of technology adoption alone, thereby extending socio-technical interpretations of transformation. Second, it identifies a persistent data–decision gap, showing that increasing data availability does not automatically lead to improved sustainability-related decision-making when digital systems remain fragmented and primarily compliance-oriented, thus complementing extant work on the enabling role of digital technologies. Third, it reframes human capital not simply as a stock of isolated skills, but as a bridging and compensatory organizational mechanism through which firms connect sustainability practices, digital infrastructures, and decision processes, thereby extending recent skills-based perspectives on the twin transition.

From a practical and managerial perspective, the findings indicate that firms should not approach digitalization as a stand-alone investment trajectory. Instead, managers should formalize cross-functional governance structures, embed sustainability data into strategic and operational decision cycles, institutionalize hybrid roles to reduce dependence on informal boundary-spanning individuals, and design training initiatives that combine digital literacy with systems thinking, data interpretation, and cross-functional coordination. In this sense, the study shows that progress in the twin transition depends less on adding more digital tools than on strengthening the organizational capability to integrate competences, infrastructures, and decision-making processes.

6. Conclusions

Human capital development is increasingly central to organizations' ability to navigate the twin green and digital transition, yet empirical insight into how sustainability-related and digital competences are mobilized in practice remains limited. This study addresses this gap through a multiple case analysis in the fashion industry, examining how sustainability practices, digital technologies, and human capital configurations interact at the organizational level.

The findings show that sustainability practices remain largely human-driven and embedded in pre-digital routines, while digital technologies are primarily adopted to support compliance and reporting. Within this configuration, human capital plays a bridging role by compensating for misalignments between sustainability ambitions, fragmented digital systems, and decision-making processes. Rather than reflecting a simple lack of skills, these dynamics point to challenges in configuring and scaling integrated competences at the organizational level.

By highlighting the compensatory role of human capital in the twin transition, this study contributes to socio-technical perspectives on sustainability-oriented digitalization and suggests that education and training initiatives should focus on integrative, practice-based capability development rather than isolated skill acquisition. While exploratory in nature, the findings provide a foundation for future research on human-centric approaches to supporting the twin green and digital transition.

This study also presents limitations that suggest avenues for future research. All cases belong to the same industrial sector, characterized by moderate levels of production automation and significant reliance on manual coordination and relational supply chain governance. This context amplifies the human-driven nature of sustainability practices observed in our findings. However, analytical transferability may extend to other discrete manufacturing sectors with intermediate levels of automation, such as aerospace assembly or complex industrial equipment manufacturing, where digital systems coexist with substantial human coordination, cross-functional integration, and supplier interdependence. In such contexts, sustainability management may still depend on the configuration of competences and the alignment between data infrastructures and organizational decision-making, potentially generating dynamics similar to the data-decision gap identified here. By contrast, in highly capital-intensive and fully automated process industries, such as chemicals, refining, or semiconductor fabrication, digital technologies are typically embedded in core operational processes, and sustainability performance is more directly linked to real-time system control and optimization. In these settings, the balance between human-driven and system-driven sustainability management may differ substantially, potentially reshaping the mechanisms observed in this study. Future comparative research across sectors with varying degrees of automation would therefore help refine the boundary conditions of the proposed framework.

Within this sectoral boundary, as an exploratory qualitative study, the findings are not statistically generalizable but contribute to theory building and can inform future quantitative and longitudinal research. A

promising avenue for further investigation concerns the development of large-scale survey-based studies comparing fast and slow fashion configurations. This quantitative research could systematically examine how the twin transition is perceived, structured, and operationalized across different business models, enabling statistical comparison of competence configurations, governance mechanisms, and digital-sustainability integration practices. Conducting such investigations within well-defined industrial ecosystems, such as geographically concentrated fashion districts, could provide contextual depth while enhancing the international relevance and generalizability of the findings.

Finally, the reliance on managerial informants suggests the value of incorporating additional perspectives, such as operational roles, suppliers, and technology partners, to further investigate how competence integration unfolds across organizational and supply-chain boundaries over time.

CRediT authorship contribution statement

Ilaria Bucci: Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Virginia Fani:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation, Conceptualization. **Monica Rossi:** Writing – review & editing, Validation, Supervision. **Romeo Bandinelli:** Writing – review & editing, Validation, Supervision.

Declaration of generative AI and AI-assisted technologies in the manuscript preparation process

During the preparation of this work the authors used ChatGPT 5 in order to revise English. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

APPENDIX

Table 1A
Interview Protocol

Main area	Guiding questions
Introductory information	• Company description (size, positioning, supply chain structure) • Interviewee role and responsibilities
Interview Body	• What kind of sustainability or "green" initiatives are you currently implementing that do not rely on digital technologies? • Which of these practices have been most impactful or relevant in your context? • Which digital technologies are currently being used to support environmental or sustainability goals? • Can you provide examples of sustainability practices enabled or enhanced by technology? • Are digital tools mainly used for compliance/data tracking or also for consumer-facing transparency? • How could digital technologies further improve or scale your sustainability initiatives? • Are there technological solutions you plan to adopt to strengthen your green transition? • Do you perceive a lack of sustainability-related knowledge or skills? • Do you observe shortages in digital or technological competences? • Is there a lack of hybrid skills connecting technology and sustainability? • How does the organization address competence gaps? • How are sustainability and digital functions integrated within the organization? • What organizational challenges limit integration between sustainability and digital systems?

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