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# Enabling digital circular economy in the agri-food sector: A socio-technical, process-based framework

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## HIGHLIGHTS

- Develops a socio-technical, process-based framework explaining organisational digital circular economy practices.
- Articulates analytical domains through which digital circular economy initiatives are enacted.
- Develops socio-technical enablers explaining their configurational arrangements.
- Provides a self-diagnosis tool to support practitioners' strategic engagement with digital circular economy practices.

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## ABSTRACT

Agri-food companies face increasing pressure to improve resource efficiency, reduce waste, and transition towards circular economy practices. Digital technologies offer important opportunities to support circular economy initiatives, a phenomenon increasingly discussed as digital circular economy, yet limited attention has been paid to how digital circular economy practices are organisationally enabled. This study aims to explain how digital circular economy initiatives are generated and sustained through socio-technical enablers in agri-food sector organisations. Drawing on socio-technical systems theory, we adopt a qualitative research design based on semi-structured interviews with 27 agri-food sector professionals affiliated with 16 companies in New Zealand and Japan. The interview data were analysed using reflexive thematic analysis informed by critical realism. We develop 11 empirically grounded socio-technical enablers organised into two analytical domains, Preparatory and Operational. This study contributes to digital circular economy and wider digital sustainability research agenda by moving beyond factor identification and developing a socio-technical and process-based framework for explaining digital circular economy implementation at the organisational level. It concludes that digital circular economy implementation depends not only on the adoption of digital technologies, but also on the co-development of digital and circular economy-oriented socio-technical conditions within and beyond organisational boundaries. The framework is further translated into a self-diagnosis tool to support professionals in reflecting on organisational conditions and prioritising actions for digital circular economy implementation.

## 1. Introduction

The world population is projected to grow from 8.2 billion in 2024 to a peak of 10.3 billion by the mid-2080s, despite declining global fertility rates (United Nations Department of Economic and Social Affairs, 2024). The agri-food sector therefore faces increasing pressure to supply food for both current and future populations. Significant inefficiencies persist across food supply chains: Approximately 13.3% of food is lost between post-harvest handling and distribution (FAO, 2023), with a further 2.3% wasted at retail (UNEP, 2024). Environmental pressures are further intensified by extensive plastic use and only 9% of total plastic waste is recycled worldwide (OECD, 2022a). At least 14% of global plastic consumption is associated with the agri-food sector (FAO, 2021). Moreover, much food packaging remains commercially unfeasible to recycle due to safety and material constraints (Geueke et al., 2018). Collectively, these challenges indicate that linear agri-food supply chains cannot simultaneously secure food, sustain ecosystems, and raise productivity.

These pressures have increased interest in circular economy (CE) approaches in agri-food systems. One emerging approach is the use of

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advanced digital technologies associated with Industry 4.0 (I4.0), hereafter referred to as Industry 4.0 technologies (I4.0Ts), to enable and accelerate this transition. In this study, such activities are referred to as digital CE initiatives or practices (Papalexi et al., 2026). Digital CE initiatives have been increasingly observed among agri-food sector companies. For example, the World Economic Forum (n.d.) reports that several global food processing companies are pursuing digitally enabled CE practices. At Mondelēz International's Beijing factory, the implementation of I4.0Ts resulted in a 53% improvement in labour productivity alongside a 29% reduction in food waste. Similar developments are also evident in the agricultural industry (OECD, 2022b). Nevertheless, a substantial gap remains between firms' recognition of the importance of digital CE and their actual implementation (Gartner, 2020).

Existing research has paid limited attention to how CE initiatives are enacted through the implementation of digital technologies within companies. Prior studies have often conceptualised digital technologies and their functionalities as enablers of digital CE practices (e.g., Rajput and Singh, 2019). More recent research focusing on the agri-food sector has attempted to address this issue by identifying individual technological or social enablers of digital CE practices (e.g., Ersoy et al., 2022), as well as by mapping barriers to their implementation (e.g., Ada et al., 2021; Kumar et al., 2022). While these studies provide valuable insights, they largely remain at the level of factor identification, offering limited explanation of how such factors generate digital CE practices within companies.

However, prior research on the use of I4.0Ts suggests that digital CE practices, when enacted in organisations, are shaped by interactions between technical and social aspects (Davies et al., 2017). Evidence from the broader digital transformation literature further indicates approaches that overemphasise technology frequently fail to achieve their intended outcomes. For example, Tabrizi et al. (2019) report that more than two-thirds of digital transformation initiatives do not meet their objectives due to a lack of focus on their social and organisational aspects. Against this backdrop, the limited understanding of how digital CE initiatives are generated and sustained through the interplay between technological and social factors represents a significant gap in existing research.

To address this research gap, this study adopts socio-technical systems theory, rooted in foundational work on the joint optimisation of social and technical systems (Mumford, 2006; Trist and Bamforth, 1951), as its primary theoretical lens (Dehe et al., 2026b) and focuses on socio-technical enablers as the central analytical unit. These enablers are conceptualised as recurring socio-technical patterns that shape how digital CE initiatives are formed and enacted in organisational practice. Accordingly, this study asks the following research question:

> RQ: "How do digital CE practices in agri-food sector companies emerge and become sustained through socio-technical enablers?"

More specifically, this study aims to explore, explain, and theorise these patterns at the organisational level.

This study adopts a qualitative research design informed by a critical realist orientation to identify the socio-technical enablers underpinning digital CE practices in the agri-food sector. Empirical data were collected through purposeful sampling, with participants recruited via direct contact and complementary referral-based sampling. In total, 27 practitioners from 16 agri-food sector companies in New Zealand (NZ) and Japan (JP) were interviewed. Semi-structured interviews were conducted using an interview protocol informed by a modified hexagonal socio-technical systems framework developed for this research (see Fig. 1). The interview data were analysed using reflexive thematic analysis informed by critical realism (CR) (Braun and Clarke, 2006, 2019, 2021; Fletcher, 2017).

This study contributes to digital CE research by developing an empirically grounded socio-technical, process-based framework that explains how digital CE initiatives are formed, enacted and reinforced within companies. Rather than treating enablers as isolated technological or social factors, the framework integrates 11 socio-technical enablers across Preparatory and Operational domains and explains how

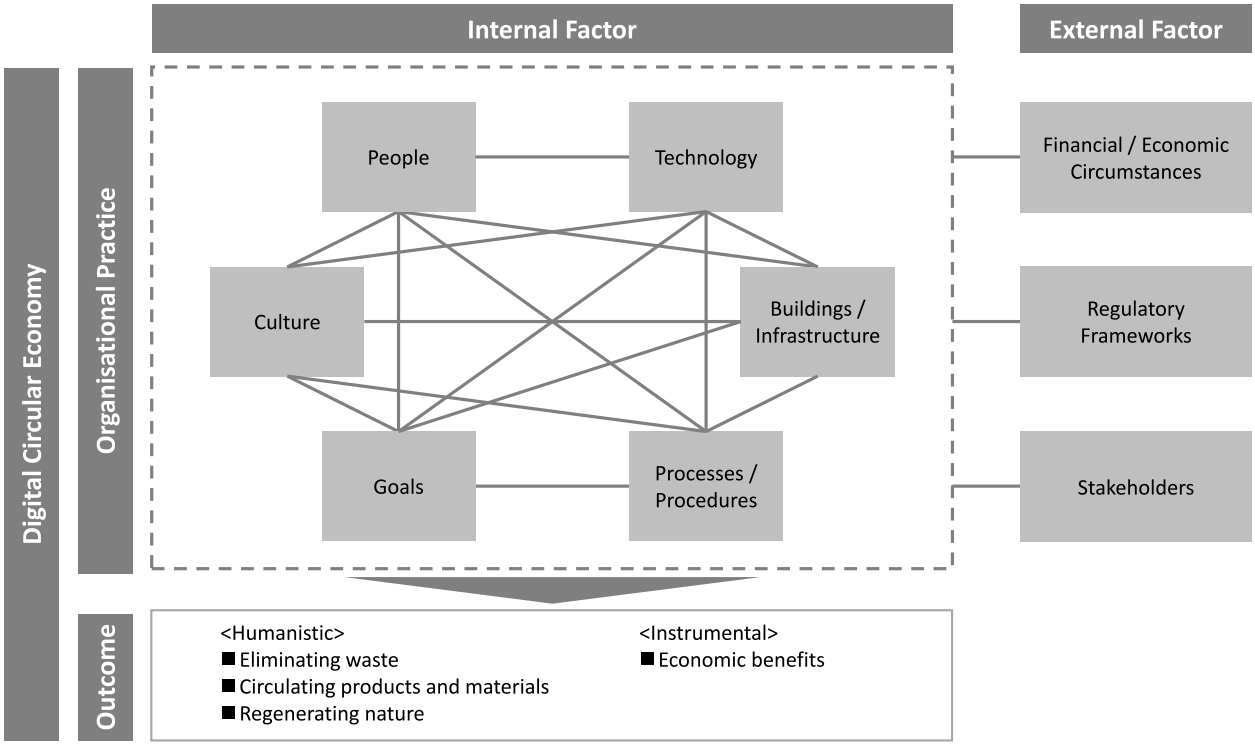



**Fig. 1.** Modified hexagonal socio-technical systems framework for analysing digital circular economy practices.
Note. Adapted from Davis et al. (2014), Ellen MacArthur Foundation (2024), Lieder and Rashid (2016), and Sarker et al. (2019).

their configurational arrangement shapes digital CE implementation. In addition, the study develops a self-diagnosis tool grounded in this framework to facilitate practitioners' strategic engagement with digital CE implementation.

## 2. Literature review

### 2.1. Digital circular economy

Prior research has established a positive relationship between advanced digital technologies and CE. A systematic literature review by Rosa et al. (2020), covering 158 studies published between 2013 and 2018, demonstrates that I4.0Ts support CE through resource optimisation, product lifecycle management, closed-loop supply chains, sustainable production processes, and the development of new business models. An empirical study by Laskurain-Iturbe et al. (2021) similarly found that I4.0Ts, despite variation across technologies and CE domains, overall contribute significantly to firms' circularity outcomes.

However, while this growing body of evidence has clarified the performance implications of digital technologies for CE, research examining the relationship between digital technologies and CE, or the broader concept of sustainability, has progressed in a fragmented manner, lacking a unifying conceptual umbrella (Kotlarsky et al., 2023). Across disciplines, concerns have been raised that fragmented terminologies and parallel debates hinder cumulative theoretical development. For example, information systems research has highlighted the proliferation of partially overlapping concepts (e.g., Green IT and Green IS) and called for conceptual integration under the notion of digital sustainability (George et al., 2021; Kotlarsky et al., 2023).

This study is positioned within these integrative efforts and examines the convergence of digital technologies and CE through the concept of digital CE. Rather than introducing an additional sustainability concept, the study adopts digital CE as an analytically focused subset of digital sustainability, centring specifically on CE practices as a concrete and organisationally observable domain of sustainability. However, digital CE itself remains underdeveloped and is not used consistently in prior research. While Kristoffersen et al. (2020) refer to digital CE as an analytical point of departure, the concept is not explicitly defined or stabilised, and similarly, Piscicelli's (2023) recent review discusses digital CE impacts without offering a clear definition of the concept.

Accordingly, this study adopts a working definition of digital CE by building on Kotlarsky et al.'s (2023) definition of digital sustainability and integrating it with the CE principles articulated by the Ellen MacArthur Foundation (2024). Digital CE is thus defined as *the development and deployment of digital resources and artefacts toward eliminating waste and pollution, circulating products and materials, and regenerating nature.* Importantly, while Kotlarsky et al. (2023) primarily focus on the development and deployment of digital technologies per se, this study adopts a broader working interpretation that encompasses organisational factors such as the reconfiguration of information, resources, and decision-making processes required to achieve circularity.

In this study, digital CE is examined at the level of organisational practice. In empirical terms, these practices are closely associated with the organisational adoption and use of I4.0Ts and related data infrastructure (Shayganmehr et al., 2021). Given the lack of consensus regarding the boundaries of I4.0Ts (e.g., Beier et al., 2020; Frank et al., 2019), this study adopts an intentionally broad understanding of I4.0Ts and does not restrict the analysis to a predefined set of digital artefacts.

### 2.2. Digital circular economy initiatives in the agri-food sector

This study focuses on digital CE practices within the agri-food sector as its primary sectoral scope. As Kumar et al. (2022) note, the agri-food sector faces the dual challenge of supplying food not only for the current but also for a rapidly growing future global population. At the same time, food systems are characterised by high sensitivity to quality and safety requirements, as well as perishability of food which makes storage and handling particularly challenging. As a result, it is estimated that approximately one-third of food is lost or wasted across supply chain processes. Beyond food itself, packaging plays a critical role in maintaining food quality and safety, yet consumer understanding of the environmental impacts associated with food packaging remains limited (Otto et al., 2021). This context underscores the importance of digital CE for agri-food sector companies, as it represents the intersection of CE approaches aimed at reducing food loss and waste, and digital technologies that provide potential solutions to support such efforts. For example, Iqbal and Kang's (2024) study illustrated how Internet of Things (IoT) can support food storage and rotation practices, as well as facilitate the recycling of food loss and waste in agri-food contexts.

One prominent stream of digital CE research has sought to examine how digital CE functions, or is hindered, within specific implementation contexts. This stream has often been shaped by a technology-centred perspective and by analytical approaches that prioritise the identification and listing of enabling or constraining factors. A representative example is provided by Rajput and Singh (2019), who, through a survey of manufacturing firms, identify 26 factors enabling digital CE practices and 15 factors hindering them in list form. In a similar vein, Mastos et al. (2021) investigate three empirical cases of I4.0T deployment, demonstrating how digital technologies can support the implementation of circular supply chain management in real-world settings. Notably, the factors identified in their study are predominantly technical or technological in nature.

Although research on digital CE practices in the agri-food sector remains limited, it has gradually begun to expand in recent years. Among the emerging contributions, Ada et al. (2021), through a systematic review, and Kumar et al. (2022), through a quantitative investigation, comprehensively identify barriers to digital CE practices in the agri-food sector. Furthermore, Ersoy et al. (2022) identify and categorise both technical and social factors that influence the use of digital information-sharing technologies in the development of circular supply chains in the meat industry. While these studies extend attention beyond purely technical considerations to include social factors, an important limitation remains. Even where barriers and enablers are comprehensively identified, factor-based listings offer limited explanations of how digital technologies are translated into practice through organisational dynamics within individual firms. This suggests the need for a perspective that moves beyond factor identification to explain how multiple social and technical elements interact over time to generate and sustain digital CE practices at the organisational level.

### 2.3. Socio-technical perspectives on digital circular economy practices and their enablers

Digital CE constitutes not only a technological phenomenon but also a fundamentally social and organisational one (e.g., Bag et al., 2021). Davies et al. (2017) conceptualise I4.0 as "a complex interaction between humans, machines and the environment aspects of organisational systems" (p. 1293), highlighting that operational outcomes depend on the interplay between social and technical elements rather than on I4.0Ts alone. Practitioner-oriented analysis similarly emphasises the socio-technical nature of digital transformation. For example, Tabrizi et al. (2019) report that more than two-thirds of corporate digital transformation initiatives fail due to insufficient attention to social and organisational aspects. Taken together, these insights suggest that digital CE practices cannot be adequately explained through technological adoption or constraint-based explanations alone. Instead, they call for a socio-technical perspective that examines how digital technologies acquire meaning and become embedded within organisational practices.

This study seeks to explain this process through the concept of socio-technical enablers. Prior research in organisational studies and information systems suggests that technology-related practices depend on recurring interactions between material, organisational and human

elements (e.g., Feldman and Pentland, 2003; Leonardi, 2011). Building on this insight, this study conceptualises socio-technical enablers as recurring socio-technical patterns that shape how digital CE initiatives are formed and enacted in organisational practice. This definition shifts attention from individual factors to the patterned interrelations through which digital technologies, organisational arrangements, user practices, and CE objectives become connected in practice.

An implementation perspective further helps explain why such enablers should not be treated as static or isolated conditions. IT implementation research has long shown that digital implementation unfolds across multiple stages, from initiation and adoption to adaptation, acceptance, routinisation, and infusion (Cooper and Zmud, 1990). Similarly, research on organisational readiness for change emphasises that implementation depends on multifaceted and context-specific conditions across pre- and post-implementation stages (Weiner, 2009). This implementation-oriented view indicates that digital CE implementation involves both preparatory processes through which initiatives are initiated and developed, and operational processes through which they are enacted, adjusted, and embedded in everyday organisational routines.

Building on this distinction, this study further draws on process and configurational thinking to explain how socio-technical enablers shape digital CE initiatives over time and in combination. Organisational phenomena can be understood as unfolding over time through sequences, events and interactions (Langley, 1999; Van de Ven, 1992), while organisational outcomes are also shaped by interdependent combinations of elements, rather than isolated factors (Fiss, 2007). Applied to digital CE, this view supports an analytical focus on how multiple socio-technical enablers are dynamically configured under particular organisational and contextual conditions. This provides the theoretical basis for examining how digital CE initiatives are formed, enacted, and reinforced through the configurational arrangements of socio-technical enablers over time.

### 2.4. Hexagonal socio-technical systems theoretical framework for digital circular economy

To theorise the socio-technical enablers that generate and sustain digital CE practices, this study adopts socio-technical systems (STS) theory as its primary theoretical lens. STS theory is rooted in foundational work on the interdependence and joint optimisation of social and technical systems in organisational work (Mumford, 2006; Trist and Bamforth, 1951), and has more recently been extended to digital and I4.0 contexts (Davies et al., 2017; Dehe et al., 2026b; Sony and Naik, 2020). Building on this theoretical foundation, Davis et al.'s (2014) hexagonal socio-technical systems framework enables the present analysis by conceptualising organisational practices as shaped by the interaction of six internal social and technical factors: technology, buildings and infrastructure, processes and procedures, goals, culture, and people. The framework also takes into account the influence of three external factors, financial and economic circumstances, regulatory frameworks, and stakeholders. Together, these elements allow for a comprehensive examination of socio-technical systems such as digital CE.

However, while this framework provides a robust means of visualising organisational socio-technical configurations, in its original form, it does not explicitly incorporate an outcome perspective of the system. To address this limitation, this study draws on Sarker et al. (2019), who conceptualise the outcomes of socio-technical practices as comprising two analytically distinct yet interrelated dimensions: instrumental and humanistic outcomes. When applied to the definition of digital CE adopted in this study, humanistic outcomes can be interpreted primarily as environmental and resource-related benefits, including eliminating waste and pollution, circulating products and materials, and regenerating nature (Ellen MacArthur Foundation, 2024). At the same time, Lieder and Rashid (2016) argue that, alongside environmental and resource benefits, the realisation of economic benefits which are linked to sustainable economic activity and growth opportunities constitutes an essential objective of CE, and cannot be treated as secondary. This interpretation reflects the view that digital CE simultaneously pursues economic, environmental, and resource-related objectives.

Based on these considerations, Fig. 1 presents a modified version of the hexagonal socio-technical systems framework proposed by Davis et al. (2014), extended to explicitly incorporate both instrumental and humanistic outcomes. This adapted framework provides the theoretical foundation that informs the data collection and analysis undertaken in this study. The key attributes associated with each internal factor are summarised in Table 1, where they are elaborated in greater detail. External factors are treated as contextual conditions rather than focal analytical categories. Building on this theoretical foundation, the following section outlines the methodology adopted in this study.

## 3. Methodology

### 3.1. Qualitative research design

This study adopts a qualitative research design informed by a critical realist (CR) orientation, which views socio-technical practices as outcomes of underlying mechanisms that generate tendencies under particular organisational conditions and can be interpreted through practitioners' accounts and experiences (Danermark et al., 2019; Fletcher, 2017). Digital CE involves complex interactions between technological and social aspects, making a qualitative approach well suited to capturing practitioners' contextualised organisational practices and examining how they develop in corporate settings (Creswell and Poth, 2018). This study is predominantly exploratory with an explanatory component. It is exploratory by addressing the limited empirical insights into digital CE enablers, and explanatory in examining the socio-technical patterns through which digital CE initiatives take shape in organisational settings. Building on the theoretical foundation established earlier, the STS lens informs the development of interview questions and to support the interpretation of interactions between social and technological aspects.

### 3.2. Data collection

#### 3.2.1. Sampling strategy

To identify participants capable of providing rich, experience-based insights into digital CE practices, this study primarily employed

**Table 1**
Key attributes of the internal factors in the modified socio-technical systems framework.

| Internal factor | Key attribute |
|---|---|
| **Technology** | Digital technologies |
| **Buildings/ Infrastructure** | Physical infrastructures (buildings, factories, machinery, equipment, hardware, transport, warehouse), and utilities (water, electricity, gas), physical and operational environments |
| **Processes/ Procedures** | Work processes and procedures, strategic planning, work designs, job roles and responsibilities, governance and control mechanisms, communication and coordination, and day-to-day practices |
| **Goals** | Financial and non-financial goals (both individual and organisational), purposes, visions, objectives, targets, commitments, KPIs, means to achieve them and priority setting |
| **Culture** | Common beliefs, collective mindsets, risk appetite, work ethics, values, psychological safety, knowledge sharing and innovation |
| **People** | Individuals, groups of individuals, their skills, competencies, expertise, attitudes, motivations, training activities, and recruiting |

Note. Adapted from Challenger et al. (2010) and Davis et al. (2014).

purposeful sampling (Dehe et al., 2026a; Dehe et al., 2026b; Patton, 2015). Inclusion criteria were established across four dimensions, namely sector stage, firm characteristics, participant attributes, and country context, to ensure that those selected were directly involved in, or had strategic oversight of, the phenomenon under investigation.

This study focused on four stages of the agri-food sector: agricultural production, processing, distribution, and retail, which broadly reflect the typical structure of agri-food supply chains (e.g., Aday and Aday, 2020; Neven, 2014; Tsolakis et al., 2014). However, inter-firm supply chain relationships were not treated as a selection criterion, as the purpose of this research was not to analyse enablers within a specific, transactionally linked supply chain.

To identify and explain the socio-technical patterns underpinning digital CE practices, it was essential to recruit participants from companies where such practices had already been implemented and were observable in organisational practice. However, such emerging practices are not uniformly present across all agri-food firms. Given the resource constraints and limited digital capabilities typically faced by small- and medium-scale enterprises (SMEs) (e.g., Dehe et al., 2026a; Scuotto et al., 2021), larger firms were prioritised during the screening process because they were more likely to provide information-rich cases in which digital CE initiatives had progressed beyond initial intention and could be examined through professionals' implementation experiences.

To ensure that interviewees possessed sufficiently rich and directly relevant experience with digital CE practices, the study applied four criteria: job field, organisational position, tenure, and recency. First, candidates working in fields such as manufacturing, operations, supply chain management, engineering, corporate planning, ICT and sustainability promotion were prioritised, given their direct relevance to digital CE practices. Second, within these fields, middle managers were prioritised because, as they are often described as "the architects of context" within organisations (Wrzesniewski and Dutton, 2001, p. 195), they were expected to provide rich accounts grounded in implementation and operational experience, while also having sufficient organisational visibility to reflect on strategic priorities, resource allocation, coordination issues, and broader implementation challenges. Third, candidates were required to have at least one year of tenure at their respective companies to ensure that they had accumulated sufficient operational and organisational knowledge to provide meaningful reflection on digital CE practices. Finally, participants were screened for the recency of their experiential knowledge to ensure they could reflect on digital CE-related practices from 2020 onwards.

Participants were recruited from agri-food sector companies in New Zealand (NZ) and Japan (JP). The inclusion of NZ and Japan served as an analytic strategy to capture contrasting organisational contexts. The aim of this study was not to conduct a cross-country comparison, but to develop a theoretically grounded and analytically transferable framework for explaining digital CE practices at the organisational level. To maintain contextual coherence, all participants were required to have professional experience in companies operating locally within the respective countries.

### 3.2.2. Recruitment procedure and data sufficiency

A total of 27 participants were recruited through a combination of direct and referral-based approaches, in line with the sampling strategy. Nineteen participants were recruited directly via LinkedIn. Approximately 150 agri-food sector companies in NZ and Japan were identified through industry databases and publicly available online sources, from which potential participants were identified and contacted with information about the study and interview expectations.

This direct approach was complemented by referral-based recruitment to access additional relevant practitioners. In total, eight participants (one in NZ and seven in Japan) were recruited through referrals, primarily via the researchers' existing professional contacts acting as gatekeepers. Across both approaches, the same inclusion criteria were applied to maintain consistency in participant selection and ensure that all participants possessed relevant experience of digital CE initiatives.

Recruitment was not guided by a predetermined sample size. Consistent with the concept of information power (Malterud et al., 2016), data collection continued until information power of the data set was considered sufficient to support an empirically grounded and theoretically informed analysis of digital CE implementation from an STS perspective. Given the focused research aim, the inclusion of participants with direct experience of digital CE initiatives, the use of an established theoretical framework, and the depth of the interview material collected across multiple organisational contexts, the final sample of 27 participants was considered sufficient to address the research objectives.

### 3.2.3. Interview protocol

Semi-structured interviews were employed to generate rich qualitative data with systematic coverage of the socio-technical aspects relevant to the study, while enabling a stance of "openness, flexibility and improvisation" (Myers and Newman, 2007, p. 14). This approach allowed topics to be explored in greater depth in response to participants' experiences and interactions. Pre-prepared key interview questions were developed, as shown in Table 2, informed by the nine socio-technical aspects represented in the modified STS framework (Fig. 1). The six internal aspects were further operationalised through the key attributes presented in Table 1 to ensure systematic coverage of relevant socio-technical conditions.

Each interview lasted between 30 and 60 min. With the exception of two face-to-face interviews, all interviews were conducted via Microsoft Teams. Interviews were carried out in either English or Japanese, according to participants' language preference. With participants' prior informed consent, all interviews were audio-recorded and transcribed verbatim. Japanese-language data were analysed in the original language, with selected quotations and analytical labels translated into English when required for reporting.

### 3.2.4. Ethical and confidentiality considerations

This study draws on qualitative data collected from participants. All participants provided informed consent prior to participation, either in written form or through recorded verbal consent. Participation was voluntary, and participants were informed of their right to withdraw at

**Table 2**
Key interview questions and associated socio-technical elements for the semi-structured interviews.

| Key Interview question | Focused socio-technical elements |
|---|---|
| 1. How and when did your company begin adopting digital technologies for CE? | **Technology, Infrastructure, Process, Goal, People, External Circumstances** |
| 2. Did you encounter unexpected challenges? How were they addressed? | **Technology, Process, Goal, People, Culture** |
| 3. How is [technology X] used in your operations? | **Technology, Process** |
| 4. How do digital technologies interact with existing physical infrastructure? | **Technology, Infrastructure** |
| 5. How are CE-related goals formulated and aligned with other corporate objectives? | **Technology, Goal** |
| 6. How were investment decisions in digital technologies in CE made? | **Technology, Process, Goal** |
| 7. How does your corporate culture influence the use of the digital technologies in CE? | **Technology, Culture** |
| 8. How does your company acquire digital skills and digitally capable personnel? | **Technology, People** |
| 9. How do regulatory settings shape or constrain CE-related digital capability building? | **Technology, People, Regulatory Frameworks** |
| 10. Who are the key stakeholders, and how do they influence digital CE-related practices? | **Technology, Process, Stakeholders** |

any time without consequences.

The interviews were conducted between October 2024 and September 2025. Ethical approval for the study was granted in advance by the AUT Ethics Committee (AUTEC) on 30 July 2024 (Reference No: 24/170). To protect confidentiality and privacy, all company and participant identifiers were anonymised, and the data were securely stored in accordance with institutional ethical guidelines.

#### 3.2.5. Participants

Table 3 outlines the key attributes of the 27 research participants (NZ-1 to NZ-13 and JP-1 to JP-14), representing 16 companies (NZ-C1 to NZ-C8 and JP-C1 to JP-C8). One exception is JP-13, which refers to a small group interview involving two practitioners from the same department. As their accounts reflected shared experiences and mutually complementary perspectives, the interview was treated as a single analytical unit and reported as one participant. The participants span multiple stages of agricultural production, processing, distribution, and retail, and represent a range of functional roles. Together, the sample reflects variation in professional experience and organisational size, providing a broad empirical basis for examining digital CE practices at the organisational level across diverse organisational contexts.

### 3.3. Data analysis

#### 3.3.1. Analytical strategy

This study adopted reflexive thematic analysis (RTA) as its data analysis approach. Rather than prioritising coding consensus, RTA emphasises researcher subjectivity as a central analytical resource, enabling the generation of theoretically informed and empirically grounded interpretations through systematic engagement with data within a particular context (Braun and Clarke, 2019). In this study, RTA was employed in a manner consistent with a CR emphasis on abduction and retroduction as modes of inquiry for exploring underlying socio-technical conditions (Danermark et al., 2019; Fletcher, 2017). This approach allows empirical accounts of participants' experiences to be analytically reconstructed as interpretive narratives that illuminate underlying organisational contexts.

Table 4 summarises the analytical process through which interview data were progressively abstracted from STS-informed codes to the identified enablers. The enablers were subsequently integrated into a process-based framework through CR-informed analysis. The empirical material associated with each enabler was then reinterpreted to develop key analytical elements, which supported the construction of the analytical narrative in the findings. The qualitative data analysis software NVivo (version 15) was employed to support the systematic management and integration of interim analytical insights throughout the analysis.

#### 3.3.2. Coding and theme development

Following the analytical strategy outlined above, coding and theme development were conducted using RTA informed by an STS lens. Initial coding adopted a deductive approach guided by the nine aspects of the modified STS framework presented in Fig. 1. These aspects served as an initial coding framework for identifying socio-technical conditions relevant to digital CE implementation, resulting in the development of 420 STS-informed codes. Subsequently, these coded STS attributes were clustered and abstracted into 86 sub-themes representing

**Table 4**
Analytical process for developing the socio-technical enabler framework.

| Stage | Analytical process | Output |
|---|---|---|
| **1. Data familiarisation** | Repeated reading and memoing | Familiarity with interview data |
| **2. STS-informed coding** | Initial coding of socio-technical conditions | 420 STS-informed codes |
| **3. Sub-theme development** | Clustering and abstraction | 86 sub-themes |
| **4. Theme development** | Comparison and aggregation of related sub-themes | 11 socio-technical enablers |
| **5. CR-informed framework development** | Abduction, retroduction and integration of themes | Process-based enabler framework |
| **6. Narrative development** | Interpretation and articulation of the socio-technical enablers | 29 key analytical elements |

Note. Adapted from Braun and Clarke (2019) and Fletcher (2017).

**Table 3**
Research participants and company characteristics by agri-food sector stages.

| Stage | Participant ID | Field of work | Years of experience | Company ID | Industry | No of employees |
|---|---|---|---|---|---|---|
| **Agricultural production** | NZ-10 | Digital/IT | 20 – 29 | NZ-C1 | Fresh produce | 1000 – 4999 |
| | JP-9 | Executive management | 40 – | JP-C1 | Livestock farming | 50 – 249 |
| | JP-12 | Corporate planning | 10 – 19 | JP-C2 | Seafood | 1000 – 4999 |
| **Processing** | NZ-2 | Operations | 20 – 29 | NZ-C2 | Dry processed food | 500 – 999 |
| | NZ-5 | Supply chain | 20 – 29 | | | |
| | NZ-8 | Manufacturing | 10 – 19 | | | |
| | NZ-1 | Supply chain | 5 – 9 | NZ-C3 | Wet processed food | 1000 – 4999 |
| | NZ-13 | Supply chain | 5 – 9 | | | |
| | NZ-3 | Supply chain | 10 – 19 | NZ-C4 | Dry processed food | 500 – 999 |
| | NZ-6 | Manufacturing | 10 – 19 | | | |
| | NZ-4 | Sustainability | 10 – 19 | NZ-C5 | Dry processed food | 500 – 999 |
| | JP-1 | Engineering | 30 – 39 | JP-C3 | Dairy processed food | 1000 – 4999 |
| | JP-2 | Sustainability | 20 – 29 | | | |
| | JP-3 | Supply chain | 30 – 39 | | | |
| | JP-4 | Supply chain | 20 – 29 | | | |
| | JP-5 | Manufacturing | 20 – 29 | | | |
| | JP-6 | Digital/IT | 20 – 25 | JP-C4 | Dry processed food | 500 – 999 |
| | JP-13 | Engineering | 10 – 19 | | | |
| | | | 5 – 9 | | | |
| | JP-14 | Supply chain | 20 – 29 | | | |
| | JP-11 | Digital/IT | 10 – 19 | JP-C5 | Confectionery processed food | 1000 – 4999 |
| **Distribution** | NZ-11 | Digital/IT | 5 – 9 | NZ-C6 | Distributor | 250 – 499 |
| | JP-7 | Sustainability | 30 – 39 | JP-C6 | Distributor | 1000 – 4999 |
| **Retail** | NZ-9 | Sustainability | 20 – 29 | NZ-C7 | Supermarket | 5000 – |
| | NZ-12 | Supply chain | 5 – 9 | | | |
| | NZ-7 | Sustainability | 5 – 9 | NZ-C8 | Supermarket | 5000 – |
| | JP-10 | Digital/IT | 20 – 29 | JP-C7 | Convenience store | 1000 – 4999 |
| | JP-8 | Corporate planning | 10 – 19 | JP-C8 | Supermarket | 1000 – 4999 |

organisational-level patterns of meaning. Through repeated comparison of sub-themes across organisational contexts and national datasets, 11 socio-technical enablers were developed. In line with Braun and Clarke's (2021) conceptualisation of themes, these themes were constructed not to maximise classificatory completeness, but to capture coherent and multi-faceted patterns of meaning regarding the socio-technical conditions shaping digital CE initiatives. To illustrate how coding and theme development were conducted in practice, Table 5 presents a selected excerpt from the analytical pathway through which empirical quotations were interpreted into STS-informed codes, sub-themes, and a socio-technical enabler.

Throughout the analytical process, coding was undertaken shortly after each interview was conducted, facilitating continued reflexive engagement with the emerging dataset. As analytical understanding developed over time, codes, sub-themes and themes were repeatedly reviewed, revised, merged, split, and relabelled through ongoing reinterpretation of interview transcripts (Braun and Clarke, 2019). Analysis of the NZ dataset was undertaken first, allowing initial analytical patterns to be developed before being examined through subsequent analysis of the Japanese dataset. Similar themes emerged across both national datasets, providing additional support for the coherence and potential analytical transferability of the identified socio-technical patterns.

**Table 5**
Illustrative example of coding and theme development for the socio-technical enabler O1 management commitment.

| Representative quotation | STS-informed code | Sub-theme | Socio-technical enabler |
|---|---|---|---|
| "*[The CIO] presents a clear vision […] and brings in the necessary budgets and resources. That is why things are working well at the moment.*" (JP-6) | CIO-led strategic vision and resource mobilisation (JP-6) | Articulating leadership direction and commitment (JP-6) | Management commitment |
| "*Senior leaders provide the vision, and we as managers think about how to achieve it. Our role is then to bring our team members along with us. This division of roles is working well at the moment.*" (JP-6) | Leadership articulation of vision (JP-6) | | |
| "*[…] how we are set up for success. It's very much around governance […].*" (NZ-4) | Strong sustainability governance structure (NZ-4) | Enhancing governance to oversee CE-related delivery (NZ-4) | |
| "*There is one global system [for data storage and management … promoted] centralised so, as governed by the Head Office […].*" (NZ-4) | Centralised initiative for data management (NZ-4) | | |
| "[In our department,] we always ask each person in charge to consider how we can better address conflicts between different requirements across departments." (JP-12) | Strategic challenge resolution through digital CE (JP-12) | Committing to addressing strategic challenges through digital CE (JP-12) | |

#### 3.3.3. Framework and narrative development

Framework development involved the use of abduction and retroduction, analytical modes of inference associated with CR and compatible with RTA (Danermark et al., 2019; Fryer, 2022). This analytical process supported the development of a processual explanation of how socio-technical enablers shape the formation and enactment of digital CE initiatives. An initial framework was developed from the NZ dataset in which the enablers were organised into two higher-order domains, Preparatory and Operational, reflecting their primary role in supporting either the initiation of digital CE initiatives or their ongoing enactment in practice. Subsequent analysis of the Japanese dataset revealed a broadly similar configuration of socio-technical enablers and domain structure, providing additional support for the coherence of the emerging framework. The two datasets were therefore integrated to develop a unified framework, as presented in Section 4.

To support the development of an analytical narrative explaining the formation of digital CE initiatives in practice, this study further identified 29 key analytical elements representing particularly salient empirical characteristics of the socio-technical enablers. The integration of the NZ and Japanese datasets required renewed engagement with the empirical evidence underlying each enabler. Through iterative reinterpretation of the data, more specific analytical bases were first identified within each enabler-specific dataset. The analytical bases refer to salient empirical characteristics in the interview data that explain the internal analytic structure of each socio-technical enabler. They were then compared, clustered, and abstracted based on shared patterns of meaning, leading to their reconstruction as key analytical elements (see Tables 7 and 8). The findings presented in the following section are organised around these key analytical elements.

## 4. Findings

### 4.1. Overview of the socio-technical enabler framework

This section presents the findings of the study. Drawing on the analytical process outlined in the previous section, the analysis developed 11 socio-technical enablers organised into two higher-order domains, Preparatory and Operational. Table 6 summarises the theme development process and presents representative quotations from the empirical data. In this study, socio-technical enablers are conceptualised as recurring socio-technical patterns that shape how digital CE initiatives are formed and enacted in organisational practice. The findings are presented through key analytical elements that capture the most analytically salient empirical characteristics associated with each enabler in the interview data.

Based on their primary role in digital CE implementation, the enablers were organised into two conceptual domains. Preparatory enablers primarily support the initiation of digital CE initiatives, whereas Operational enablers are more closely associated with their enactment and ongoing operation in practice. For clarity, the enablers are labelled sequentially as P1-P4 (Preparatory) and O1-O7 (Operational).

### 4.2. Preparatory Domain

Table 7 presents the socio-technical enablers and key analytical elements that constitute the Preparatory domain of the integrated framework, together with their associated analytical bases, which provide empirical support for the analytical interpretation of each enabler.

Need-benefit alignment (P1) is defined by three key analytical elements: significance, solutions for operational issues, and user benefits. Participants stressed that digital CE initiatives need to be meaningful not only in ethical or environmental terms but also in economic rationale, including cost justification and return on investment. Participants also indicated that digital CE becomes persuasive when it helps resolve existing operational pain points, as one participant noted: "*I think the best approach is to address the issues that frontline staff are already experiencing,*

**Table 6**
Socio-technical enablers, associated sub-themes and representative quotations from the interview data.

| Domain | Socio-technical enabler | Sub-theme (Participant ID) | Representative Quote (Participant ID) | Theme ID |
|---|---|---|---|---|
| **Preparatory** | **Need-benefit alignment** | Justifying digital CE (NZ-8); rendering adoption reasonable (NZ-11); reducing operational burden (JP-12); aligning benefits with operational realities (JP-1); linking digital CE to operational goals (JP-11); improving overall operations and costs (NZ-10); articulating value and benefits to users (JP-10). | ■ *"I think the best approach is to address the issues that frontline staff are already experiencing, but in a sustainability context"* (JP-12).<br>■ *"If you say to them '[…] the new system is gonna make your life easier […]', then people more likely will adapt"* (NZ-11). | P1 |
| | **Time & resource allocation** | Ensuring sufficient time and budget (NZ-8); providing expert ICT support (NZ-4); building acceptability through training (NZ-12); allocating personnel with operational expertise to digital CE (JP-13); dedicating personnel to data use (JP-5); providing iterative and improved training (JP-6); supporting digital skill building (NZ-13). | ■ "*those who has only worked with [digital] systems with no factory experience cannot really see what is happening in the factory*" (JP-13).<br>■ "*the initial resistance was [because the task was] handed over without training*" (NZ-8). | P2 |
| | **Engagement** | Demonstrating empathetic leadership (JP-14); fostering information sharing (NZ-4); aligning internal stakeholder interests (JP-3); engaging frontline operations through empathy (JP-2); enhancing engagement through employee care (NZ-2). | ■ "*[Leaders remove the barriers] themselves through their own statements [and actions]*" (JP-14).<br>■ "*no matter how much you push from the top, it won't resonate unless frontline staff genuinely buy into it. […] The key is gaining their empathy*" (JP-2). | P3 |
| | **Operability** | Creating inclusive and accessible systems (NZ-7); ensuring room for customisation (JP-13); designing systems with stakeholder engagement (NZ-1). | ■ "*If you shape production processes to around the [readymade] system, you risk losing what makes the company distinctive*" (JP-13).<br>■ "*The staff were like, 'oh, we like this. It makes our life easier'*" (NZ-7). | P4 |
| **Operational** | **Management commitment** | Articulating leadership direction and commitment (JP-6); enhancing governance to oversee CE-related delivery (NZ-4); committing to digital (I4.0) transformation (NZ-11); committing to addressing strategic challenges through digital CE (JP-12). | ■ "*[The CIO] presents a clear vision […] and brings in the necessary budgets and resources. That is why things are working well at the moment […]*" (JP-6).<br>■ "*[…] how we are set up for success. It's very much around governance […]*" (NZ-4). | O1 |
| | **Holistic approach** | Adopting a long-term, cross-boundary perspective (JP-7); strengthening brand value (JP-2); setting strategic environmental goals (NZ-10); aligning economic and environmental activities (JP-10). | ■ "*if we can openly communicate that prices may increase but this reflects our commitment to being nature-positive, customers may be more inclined to choose our products*" (JP-2). | O2 |
| | **Understanding & awareness** | Fostering awareness of sustainability commitments (NZ-4); Promoting awareness of loss and waste (NZ-2); building organisational digital competence (NZ-3); accumulating and disseminating successful digital CE experiences (JP-2); embedding digital CE knowledge internally (JP-12); leveraging industry bodies for practical knowledge (NZ-7); cultivating internal digital CE champions (JP-7); enhancing accountability through performance measurement (NZ-12). | ■ "*for most people […], it is really about understanding what our commitments are*" (NZ-4).<br>■ "*Once something works, everyone wants to jump on the winning horse […] People are really hungry for successful experience*" (JP-2). | O3 |
| | **Organisational openness** | Embedding open and accessible leadership (NZ-9); fostering a culture open to experimentation (JP-7); leveraging trust-based corporate culture (JP-13); promoting open and transparent communication (NZ-11). | ■ "*I think it's very, very open company trying new things all the time and giving chances to new technologies to be a part of their functions*" (NZ-13). | O4 |
| | **Collaboration** | Establishing collaborative arrangements with external experts (JP-9); Strengthening joint decision-making with external partners (NZ-3); accelerating collaboration with external stakeholders (NZ-4); strengthening supplier collaboration through mutual benefits (JP-14). | ■ "*It's more about giving them the high-level information first, gathering the concerns and feedback, and then finalising [our decision]*" (NZ-3).<br>■ "*This allows us to align perspectives and improve mutual understanding. [Even senior managers without a technical background] starts to understand the basics [of on-site operations] if we keep attending these meetings*" (JP-9). | O5 |
| | **Continuous improvement** | Enhancing feedback from operations (JP-4); creating a corporate culture of Kaizen (NZ-12); embedding Kaizen in digital CE practice (NZ-10). | ■ "*Continuous improvement education is required for all the stages for all the employees while executing any of the digital technologies [… because] all the updates come back from the people. Once it is tried and tested, things keep on changing and we get the updates accordingly*" (NZ-12). | O6 |
| | **Data foundation** | Allocating resources for data foundation (NZ-9); establishing unified and accessible data (JP-6); sharing accurate data internally and externally (NZ-1); transforming data and know-how into knowledge (JP-7); strengthening data collection and storage (JP-5); promoting data integration with external partners (JP-11). | ■ "*[…] when data is stored in one place and we show what can be done with it, people [from other departments] start saying, "then we could do this kind of thing [for CE], right?"*" (JP-6).<br>■ "*[…] so, it is important that I tell the demand team or sales team that when they give me a number it needs to be correct and accurate because the consequence, we make it and then we are to live with the product which may not sell*" (NZ-1). | O7 |

*but in a sustainability context*" (JP-12). Participants further highlighted the importance of tangible benefits for users, as one participant explained, "*If you say to them '[…] the new system is gonna make your life easier […]', then people more likely will adapt*" (NZ-11). Collectively, these key analytical elements reflected a recurring pattern in which digital CE initiatives were more likely to gain organisational support when broader organisational objectives were aligned with operational concerns and perceived user benefits.

Time & resource allocation (P2) is defined by three key analytical elements: staffing, training, and user support. Participants emphasised the importance of assigning internal personnel with operational expertise, and preferably digital proficiency, to ensure that the practical implications of digital CE initiatives are properly understood. As one participant explained, "*those who has only worked with [digital] systems with no factory experience cannot really see what is happening in the factory*" (JP-13). Participants also stressed the need to allocate sufficient time for intensive and context-specific training. Reflecting on a previous implementation effort, one participant noted that "*the initial resistance was [because the task was] handed over without training*" (NZ-8). In addition, participants highlighted the value of establishing expert user support to

**Table 7**
Key analytical elements and analytical bases of the enablers in the preparatory domain.

| Enabler | | Key analytical element | Analytical basis | Evidence ID |
|---|---|---|---|---|
| **P1** | **Need-benefit alignment** | ■ Significance<br>■ Solutions for operational issues<br>■ User benefits | Reasonable cost benefit; responsibility for the environment and country; operational issues and solutions; user benefits. | NZ: 8, 10, 11<br>JP: 1, 8, 10, 11, 12 |
| **P2** | **Time & resource allocation** | ■ Staffing<br>■ Training<br>■ User support | Repeated and contextualised trainings; time allowance and budget allocation; helpdesk setup; assignment of digital-savvy talent; utilisation of internal personnel with operational expertise. | NZ: 1, 4, 8, 12, 13<br>JP: 1, 5, 6, 13 |
| **P3** | **Engagement** | ■ De-siloing<br>■ Executive role-modelling<br>■ Employee buy-in | Employee recognition and care; information sharing and exchange; resolution of conflict of interest across departments; proactive executive involvement. | NZ: 2, 4<br>JP: 2, 3, 9, 14 |
| **P4** | **Operability** | ■ Customisability<br>■ Usability<br>■ User affinity | An intuitive system for all generations; easy launch, access and operability; positive user sentiment; flexibility and freedom to customise; operational compatibility. | NZ: 1, 7, 8<br>JP: 13 |

**Table 8**
Key analytical elements and analytical bases of the enablers in the operational domain.

| Enabler | | Key analytical element | Analytical basis | Evidence ID |
|---|---|---|---|---|
| **O1** | **Management commitment** | ■ Vision<br>■ Leadership<br>■ Systematic oversight | Clear vision for digital transformation; leadership by executive in charge; strong sustainability governance structure; centralised initiative for data integration. | NZ: 4, 11<br>JP: 6, 12 |
| **O2** | **Holistic approach** | ■ Systemic perspective<br>■ Reputation benefits | Cross-boundary perspective on sustainability; creating shared value (CSV); brand value. | NZ: 10, 13<br>JP: 2, 3, 7, 10 |
| **O3** | **Understanding & awareness** | ■ Knowledge<br>■ Accountability<br>■ Success stories | A basic understanding of sustainability; knowledge of digital transformation; a connection of loss and waste to operations; successful experience. | NZ: 2, 3, 4, 7, 11, 12<br>JP: 2, 4, 7, 12 |
| **O4** | **Organisational openness** | ■ Innovation culture<br>■ Executive accessibility | Pioneering spirit; embracing digital technologies; open corporate culture; open and accessible leadership. | NZ: 3, 9, 11, 13<br>JP: 7, 13 |
| **O5** | **Collaboration** | ■ Partnership<br>■ External expertise | Engagement of external partners; stakeholder development; vendor expertise; guidance from external specialists; information sharing with external partners. | NZ: 3, 4, 6<br>JP: 1, 9, 10, 14 |
| **O6** | **Continuous improvement** | ■ A culture of Kaizen<br>■ Legacy practice reframing | Evaluation and discussion; feedback from the site; overcoming legacy mindset; a culture of Kaizen. | NZ: 5, 10, 12, 13<br>JP: 4, 5 |
| **O7** | **Data foundation** | ■ Data collection<br>■ Data consolidation<br>■ Data accuracy | Data collection infrastructure; digitalisation for sustainability promotion; data for executive governance oversight; data consolidation; digitalised explicit knowledge; data accuracy. | NZ: 1,6, 9, 11<br>JP: 5, 6, 7, 11, 12 |

assist with troubleshooting and ongoing system operation. Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives were more likely to build implementation momentum when sufficient time, expertise, and support resources were allocated to facilitate learning and implementation. Participants further suggested that these investments often contributed to the development of broader organisational understanding and awareness regarding digital CE initiatives.

Engagement (P3) is defined by three key analytical elements: de-siloing, executive role-modelling and employee buy-in. Participants highlighted the importance of overcoming internal silos by coordinating operational interests such as targets and commitments across departments and fostering active information sharing. Executive role-modelling was also emphasised, particularly the need for leaders to familiarise themselves with the new systems, use them visibly and lead by example, as one participant explained, "*[Leaders remove the barriers] themselves through their own statements [and actions]*" (JP-14). Securing frontline engagement further depends on cultivating empathy, as one participant noted: "*no matter how much you push from the top, it won't resonate unless frontline staff genuinely buy into it. […] The key is gaining their empathy*" (JP-2). Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives were more likely to gain organisational commitment when engagement was fostered across organisational levels through cross-functional coordination, visible leadership involvement, and employee buy-in.

Operability (P4) is defined by three key analytical elements: customisability, usability, and user affinity. Participants stressed that digital CE systems must retain sufficient flexibility to accommodate company-specific processes and evolving business needs, as one participant explained, "*If you shape production processes to around the [ready-made] system, you risk losing what makes the company distinctive*" (JP-13). Participants also noted that users vary widely in age, language and digital proficiencies, and job roles which create challenges when interacting with new systems. Accordingly, digital CE systems need to be easy

to launch, access, and operate, minimising the cognitive burden of adoption. User affinity was also highlighted as important, particularly when users perceived systems as useful and supportive to their work. One participant illustrated this response by noting: "*The staff were like, 'oh, we like this. It makes our life easier'*" (NZ-7). Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives were more likely to be embedded in everyday operations when systems were adaptable to organisational contexts, easy to use, and positively received by users.

### 4.3. Operational Domain

Table 8 presents the socio-technical enablers and key analytical elements that constitute the Operational domain of the integrated framework, together with their associated analytical bases.

Management commitment (O1) is defined by three analytical elements: vision, leadership, and systematic oversight. Participants highlighted the need for a clear management vision for CE and digital transformation, together with senior executives' willingness to take responsibility for these strategic directions. They also emphasised the role of executive leadership in digital domains, particularly in leading decision-making and creating enabling conditions for internal stakeholders through strategic allocation of budgets, including investments in the data foundation. One participant described how the organisational climate for digital CE implementation shifted following the appointment of a new CIO at Company JP-C4: "*[The CIO] presents a clear vision […] and brings in the necessary budgets and resources. That is why things are working well at the moment […]*" (JP-6). Participants further stressed the role of governance structures and progress oversight in sustaining momentum, as one noted: "*[…] how we are set up for success. It's very much around governance […]*" (NZ-4). Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives were more likely to gain organisational traction when senior management provided strategic direction, responsible decision-making, and systemic oversight.

Holistic approach (O2) is defined by two key analytical elements: a systemic perspective, and reputation benefits. Participants stressed that organisations need to adopt a systemic perspective that integrates economic activities with efforts to reduce environmental burdens through resource efficiency and recycling. Participants noted that sustaining digital CE practices requires market acceptance, often under conditions of low margins and limited cost pass-through. Strengthening brand value and promoting the creation of shared value (CSV) were therefore described as ways to communicate environmental value and justify digital CE adoption, as one participant described: "*if we can openly communicate that prices may increase but this reflects our commitment to being nature-positive, customers may be more inclined to choose our products*" (JP-2). Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives are more likely to be sustained when organisations framed them within a broader system of economic, environmental, and reputational value.

Understanding and awareness (O3) is defined by three key analytical elements: knowledge, accountability and success stories. Participants noted that advancing digital CE practices requires the gradual accumulation of organisational knowledge about both CE and digital transformation. One participant highlighted the way in which shared understanding shapes digital CE practices, stating that "*for most people […], it is really about understanding what our commitments are*" (NZ-4). Participants also stressed the need to hold departments and employees accountable for loss and waste outcomes. Here, accountability refers to linking departmental and individual performance to these outcomes in ways that encourage critical reflection on what actions are required and why. In addition, celebrating and disseminating successful experiences internally was seen as important for sustaining organisational confidence, as one participant explained: "*Once something works, everyone wants to jump on the winning horse […] People are really hungry for successful experience*" (JP-2). Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives were more likely to become internally legitimised when employees developed shared knowledge of CE and digital transformation, recognised accountability for loss and waste outcomes, and were exposed to successful internal examples.

Organisational openness (O4) is defined by two key analytical elements: innovation culture and executive accessibility. Participants emphasised the importance of embedding a pioneering mindset within organisational culture so that firms can embrace digital CE practices without fear of radical change. One participant described such a culture as follows: "*I think it's very, very open company trying new things all the time and giving chances to new technologies to be a part of their functions*" (NZ-13). Participants also pointed to the role of executive accessibility, observing that know-who often shapes decision-making related to digital CE practices. While close relationships between executives and individual employees cannot always be assumed, participants suggested that an open and accessible stance helped reduce internal communication barriers and supported more inclusive participation in digital CE initiatives. Collectively, these key analytical elements reflected a recurring pattern in which digital CE initiatives were more likely to be explored and advanced when organisations cultivated openness to experimentation and accessible channels for decision-making.

Collaboration (O5) is defined by two key analytical elements: partnership and external expertise. Participants emphasised that collaboration with external partners is essential for complementing internal capabilities. They also highlighted the importance of strategically developing such partnerships. One participant noted that proactive information sharing with external partners supports more informed decision-making in digital CE practices: "*It's more about giving them the high-level information first, gathering the concerns and feedback, and then finalising [our decision]*" (NZ-3). Participants further underscored the role of external expertise in enhancing data analysis and supporting the effective operation of digital CE practices. One participant described how regular meetings involving senior management, frontline staff, and external agricultural specialists improved internal communication and shared understanding: "*This allows us to align perspectives and improve mutual understanding. [Even senior managers without a technical background] starts to understand the basics [of on-site operations] if we keep attending these meetings*" (JP-9). Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives were more likely to benefit from knowledge and capabilities beyond organisational boundaries when organisations developed strategic partnerships and incorporated external expertise into implementation processes.

Continuous improvement (O6) is defined by two key analytical elements: a culture of Kaizen and legacy practice reframing. Participants emphasised the role of embedding a culture of Kaizen within organisational practices related to digital CE. They also highlighted the importance of critically re-examining ways of working across employees and departments, particularly through operational evaluation and the identification of possible ways forward. One participant described this iterative process as follows:

> "*Continuous improvement education is required for all the stages for all the employees while executing any of the digital technologies […because] all the updates come back from the people. Once it is tried and tested, things keep on changing and we get the updates accordingly*" (NZ-12).

Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives were more likely to be refined and further developed when organisations embedded continuous improvement practices and critically re-examined legacy ways of working.

Finally, Data foundation (O7) is defined by three key analytical elements: data collection, data consolidation, and data accuracy. Participants stressed that digital CE implementation depends not only on

advanced digital technologies, but also on operationally critical data infrastructure such as Wi-Fi networks and sensors, to ensure comprehensive and uninterrupted data collection that captures operational realities. Data consolidation was likewise identified as critical, particularly in enabling internal data use across organisational departments. One participant described how centralised data opened up new possibilities for CE-related initiatives: "*[…] when data is stored in one place and we show what can be done with it, people [from other departments] start saying, 'then we could do this kind of thing [for CE], right?'*" (JP-6). Data accuracy was also emphasised as essential for reducing loss and waste, as one participant articulated:

> "*[…] so, it is important that I tell the demand team or sales team that when they give me a number it needs to be correct and accurate because the consequence, we make it and then we are to live with the product which may not sell*" (NZ-1).

Collectively, these key analytical elements reflected a recurring socio-technical pattern in which digital CE initiatives were more likely to be operationally supported when organisations established reliable data collection, consolidated data access, and accurate operational data.

Beyond these core elements, participants indicated that the data foundation was associated with multiple socio-technical enablers. Data use was described as facilitating governance and executive oversight, supporting a holistic understanding of economic and environmental performance through evidence-based insights, providing inputs for codified knowledge generation, informing continuous improvement efforts through insights into ongoing operations, and supporting accurate external communication and data linkage with partners. These associations suggest that data foundation operated not only as a technical infrastructure, but also as a socio-technical condition that enabled other organisational patterns to become more actionable in digital CE implementation.

### 4.4. Synthesis

Fig. 2 synthesises the preceding analysis by integrating the identified socio-technical enablers into the two analytically distinct but mutually constitutive domains. The vertical structure distinguishes the two conceptual domains, while the horizontal structure indicates the logical progression through which digital CE practices are formed and enacted in organisational practice. The upper section illustrates the Preparatory domain, comprising enablers associated with the initiation and early development of digital CE initiatives. The lower section depicts the Operational domain, comprising enablers associated with their ongoing enactment, adjustment and operation. The bidirectional arrow between the Preparatory and Operational domains does not indicate a single relationship between them. Rather, it provides a simplified representation of broader configurational relationships within and across these domains, without exhaustively mapping all possible interrelations among individual enablers.

Based on the empirical analysis, the broader configurational relationships within and across the Preparatory and Operational domains were analytically interpreted through three functional patterns: strengthening, directing, and feedback. Strengthening captures situations in which one socio-technical pattern helped create conditions for another pattern to become more actionable. Directing refers to situations in which particular organisational conditions oriented digital CE initiatives toward specific implementation priorities. Feedback denotes situations in which the enactment of digital CE initiatives reshaped organisational routines and implementation activities, thereby reinforcing further refinement and adjustment.

For example, the interrelation between O4 Organisational openness and P3 Engagement illustrates a strengthening pattern observed in NZ-9. In relation to a digital CE initiative involving the visualisation of sustainability data for efficiency gains, the participant emphasised accessibility to executive leadership, support from "the right people", and the need for "supporters to get your plan materialised". This suggests that an open corporate culture helped create conditions in which digital CE ideas could gain organisational support and move towards implementation. The interrelation between O1 Management commitment and O7 Data foundation further highlights a directing pattern observed in JP-6. Relating to a digital CE initiative involving supply chain visualisation for efficiency gains, the CIO articulated the strategic direction and mobilised the necessary budget and resources. This formed part of

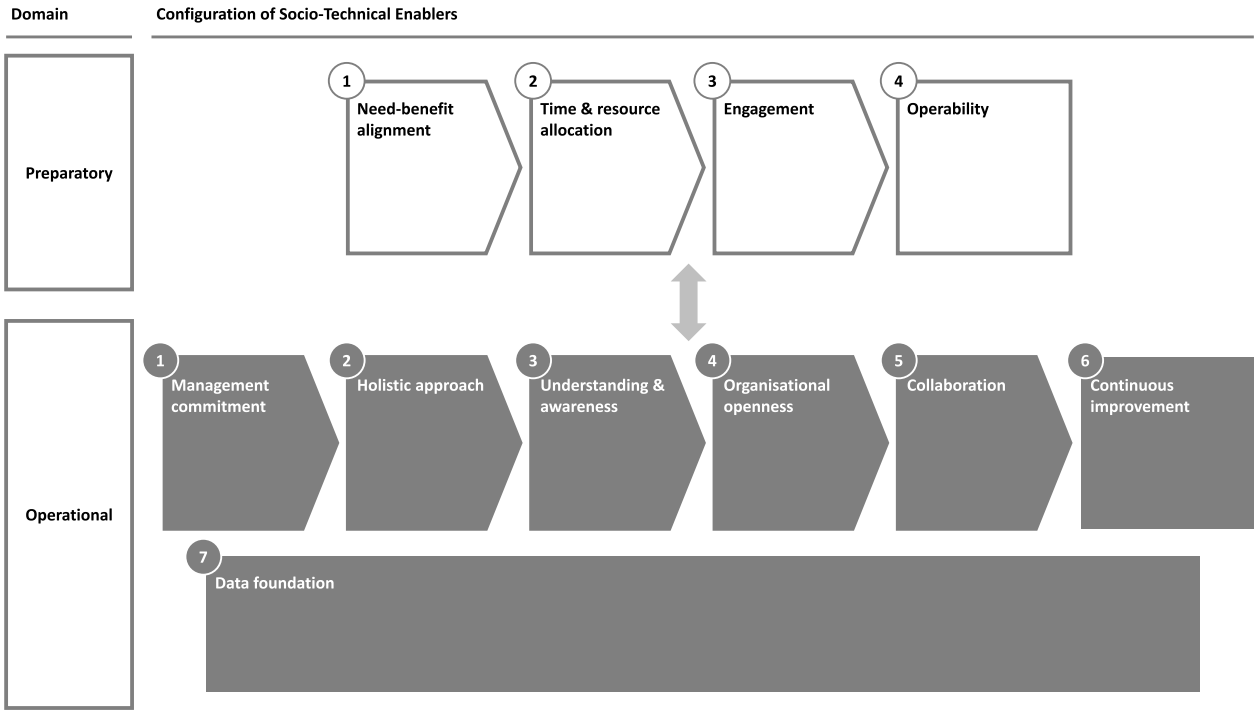



**Fig. 2.** Integrative socio-technical, process-based framework of enablers for digital circular economy practices.

the management commitment pattern associated with the development of a more integrated and accessible data foundation. The data foundation was then associated with a feedback pattern linked to O6 Continuous improvement, as employees in other departments realised that internal data were available in one place and began moving away from fragmented Excel-based work towards more data-informed operational improvement. These examples illustrate empirically interpreted pathways through which digital CE initiatives are formed, refined, and sustained in organisational practice. The following section discusses these findings in relation to the existing literature and the conceptual framing of this research.

## 5. Discussion

### 5.1. Theoretical implications

This study explains digital CE implementation not as the presence or absence of isolated enablers, but as being shaped through socio-technical enablers across the Preparatory and Operational domains. Prior studies have provided valuable insights into how Industry 4.0 and digital technologies can support CE implementation, including through implementation roadmaps and technology-enabled circular supply chain models (e.g., Liu et al., 2023; Lopes de Sousa Jabbour et al., 2018; Mastos et al., 2021). However, these accounts tend to treat implementation as a relatively integrated process, placing less emphasis on the analytical distinction between preparatory work required to initiate digital CE initiatives and operational arrangements through which they are enacted, adjusted, and embedded in practice. Building on information systems implementation research, which distinguishes between implementation process and post-adoption routinised use (Cooper and Zmud, 1990) and recognises the multifaceted and context-dependent nature of implementation across pre- and post-implementation stages (Weiner, 2009), this study distinguishes between Preparatory and Operational domains to capture different but complementary aspects of digital CE implementation. Accordingly, our Proposition 1 is articulated as follows:

**Proposition 1**. *Digital CE initiatives at the organisational level are shaped through two analytically distinct but complementary domains of socio-technical enablers*: *Preparatory and Operational*.

The findings also suggest that digital CE initiatives are shaped by the interrelations among the identified enablers rather than by the presence of individual enablers alone. Prior studies have identified various factors, barriers, drivers, and conditions associated with digital CE implementation, but have paid less attention to how these elements interact in organisational practice (e.g., Ada et al., 2021; Ersoy et al., 2022; Kumar et al., 2022; Rajput and Singh, 2019). From a process perspective, the arrangement of enablers within the two analytical domains should not be read as a fully linear implementation sequence, but as a processual ordering of socio-technical enablers through which digital CE initiatives move from early formation to ongoing organisational enactment (Langley, 1999; Van de Ven, 1992). The interrelation patterns discussed in the previous section further suggest that digital CE initiatives are configurationally shaped by the ordering of enablers within each domain and by broader relationships within and across the Preparatory and Operational domains. This is consistent with the view that organisational outcomes arise from interdependent combinations of elements rather than isolated factors (Fiss, 2007). Accordingly, our Proposition 2 is articulated as follows:

**Proposition 2**. *Digital CE initiatives are shaped and enabled through the configurational arrangements of socio-technical enablers within and across the Preparatory and Operational domains*.

From a CR perspective, such configurational arrangements may be understood as enabling mechanisms that generate tendencies, rather than deterministic outcomes, for digital CE initiatives to be formed, enacted, and reinforced under particular organisational contexts (Danermark et al., 2019). This interpretation clarifies that the enablers do not function as discrete causal factors, but as interrelated socio-technical patterns whose effects depend on their configuration in practice.

Moreover, the findings clarify what makes digital CE a distinct implementation context. Existing digital CE research has often foregrounded the role of digital technologies in enabling CE outcomes (e.g., Lopes de Sousa Jabbour et al., 2018). However, understanding digital CE implementation merely as the alignment between digital technologies as means and CE outcomes as ends provides only a partial explanation of how such initiatives are enacted in practice. Digital transformation initiatives frequently face difficulties when technological interventions are insufficiently integrated into organisational contexts, practices, and capabilities (Tabrizi et al., 2019). The present findings extend this view by showing that digital CE requires the simultaneous configuration of digitalisation and CE-oriented objectives, knowledge, accountability, and value logics. For example, O2 Holistic approach highlights the need to integrate economic activities with efforts to reduce environmental burdens through resource efficiency and recycling, while O3 Understanding & awareness indicates that organisations need to accumulate knowledge about both CE and digital transformation. Thus, the distinctiveness of digital CE lies not in the isolated adoption of digital technologies, but in the co-development of digital and CE-oriented organisational conditions that make digital CE initiatives more meaningful and actionable in practice.

This theoretical positioning also clarifies how the framework differs from implementation maturity, organisational readiness, and dynamic capability frameworks. It is not designed as an implementation maturity model because it does not specify sequential levels of organisational advancement. Nor is it an organisational readiness model, as it does not assess whether an organisation is ready to implement digital CE. Instead, it explains how socio-technical enablers connect organisational conditions, digital technologies, user practices, operational arrangements, and CE-oriented objectives in practice. Finally, while some key analytical elements, including leadership, knowledge, and innovation culture, may resemble capability-related conditions, they are treated in this study as components of broader socio-technical patterns rather than as dynamic capabilities in themselves.

Although this study was not designed as a country-comparative study, the inclusion of participants from two national contexts enabled the analysis to examine whether recurring socio-technical patterns could be observed across different organisational settings. The contribution therefore lies not in explaining national differences, but in developing a framework that may support analytical transfer across similar digital CE implementation contexts by articulating recurring socio-technical patterns. At the same time, contextual variation may shape the relative salience and activation conditions of particular enablers, rather than the overall structure of the framework.

### 5.2. Practical implications

As digital and circular initiatives become increasingly important for long-term competitiveness, many companies are still uncertain about whether the organisational conditions necessary for successful implementation are in place, or how implementation challenges can be effectively addressed. Relatively few prior studies have extended their scope to the development of framework models that can be directly applied by practitioners in organisational settings. Addressing this gap, the socio-technical enabler framework developed in this study is accompanied by a self-diagnosis tool designed to support practical engagement with the framework (see Appendix 1 for the Preparatory domain and Appendix 2 for the Operational domain). The self-diagnosis tool enables practitioners to reflect on the underlying organisational conditions through which digital CE practices are generated, sustained and reinforced within their organisations. Drawing on empirically

derived characteristics associated with each socio-technical enabler, the tool provides a set of empirically grounded, open-ended self-diagnosis questions for assessing relevant organisational conditions.

This tool is intended primarily for managers and implementation teams responsible for digital CE initiatives. It may be used either as part of ongoing organisational reflection or prior to the initiation of specific digital CE projects. A typical application could involve interviews with key stakeholders, followed by collective reflection on identified strengths and challenges and discussion of potential improvement priorities. Repeated application over time may also support monitoring organisational progress and evolving implementation needs.

To facilitate systematic reflection, practitioners are encouraged to first describe "what this element looks like in practice", before reflecting on "what the underlying issues are". To avoid excessive local optimisation, subsequent diagnosis is conducted at the level of the socio-technical enabler as a whole, guiding practitioners to consider "how the underlying issues identified can be effectively addressed." Finally, the tool invites practitioners to reflect on relative differences in potential impact and urgency across enablers when considering possible interventions, thereby supporting more strategic prioritisation of actions.

Through this structured reflection, the framework supports greater alignment across corporate strategies, including business, financial, human resource, digital, and sustainability strategies, while also facilitating collaboration among internal departments and with external stakeholders. This, in turn, allows companies to plan digital investments for CE implementation more strategically across both short- and long-term horizons.

## 6. Conclusion

### 6.1. Implications and contributions

In response to the research question of how digital CE practices emerge and become sustained in agri-food sector companies, this study develops a socio-technical, process-based framework that explains how digital CE initiatives are shaped through the dynamic configuration of socio-technical enablers. Drawing on qualitative evidence from semi-structured interviews with agri-food sector practitioners in New Zealand and Japan, the study develops 11 socio-technical enablers and 29 associated key analytical elements. Together, these findings explain how digital CE initiatives are formed, enacted, and reinforced within organisational practice.

The main theoretical contribution of this study lies in moving digital CE research beyond fragmented or factor identification-oriented accounts of implementation. Rather than treating enablers as discrete conditions whose presence or absence explains implementation outcomes, the present research conceptualises them as interrelated socio-technical patterns that operate within and across two complementary domains: Preparatory and Operational. The Preparatory domain captures enablers associated with the initiation and early development of digital CE initiatives, while the Operational domain comprises enablers associated with their ongoing enactment, adjustment, and operation. By integrating these enablers into a process-based framework, the study explains digital CE implementation as a configurational and context-dependent process rather than a purely technology-driven transition.

The findings also clarify the specificity of digital CE as an implementation context. Digital CE initiatives require not only the adoption of digital technologies, but also the co-development of CE-oriented objectives, knowledge, accountability, value logics, and organisational practices. In this sense, the study contributes to understanding how digitalisation and CE objectives become jointly configured in organisational settings.

Finally, this study contributes to practice by translating the socio-technical enabler framework into a self-diagnosis tool. The tool provides managers and implementation teams with a structured basis for reflecting on organisational conditions, identifying implementation challenges, and prioritising improvement actions. Overall, the study offers both a theoretical explanation and a practical template for understanding and supporting digital CE implementation in agri-food sector companies.

### 6.2. Limitations and directions for future research

This study defines its analytical scope as the enabling mechanisms underpinning corporate digital CE practices within the agri-food sector. While this focus does not preclude broader analytical interpretation and the mechanisms identified may inform future studies in other sectors, the findings reflect sector-specific product characteristics, business and labour practices, geographical and cultural conditions, and infrastructural constraints.

The empirical insights are derived from qualitative analysis of semi-structured interviews with 27 professionals across 16 companies and therefore do not aim at statistical generalisation or quantitative validation. Although data collection was designed to access information-rich accounts of observable digital CE implementation practices, the sample composition and the combination of direct and referral-based recruitment may have shaped who participated in the study and which organisational experiences were narrated.

The socio-technical enabler framework developed in this study suggests several directions for future research. First, future studies could further corroborate, refine, or extend the framework by examining how the socio-technical patterns are experienced and narrated in SMEs, or from the perspectives of frontline workers or senior executives. Second, future research could build on the framework and the self-diagnosis tool by empirically evaluating its practical usability in organisational settings and by developing more assessment-oriented instruments, such as frameworks for evaluating organisational readiness or maturity for digital CE implementation. Third, comparative applications in other sectors or regional contexts could support the assessment of the framework's analytical transferability beyond agri-food settings, including the identification of organisational and contextual boundary conditions under which particular socio-technical enablers become more or less salient.

## CRediT authorship contribution statement

**Taichi Arioka:** Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Resources, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Benjamin Dehe:** Writing – review & editing, Supervision, Conceptualization. **Maryam Mirzaei:** Writing – review & editing, Supervision, Conceptualization.

## Use of generative AI

The authors used generative artificial intelligence tools to support brainstorming at the design stage, and then for the refinement of language and expression during the writing process. The authors take full responsibility for the content of this manuscript, including the analysis, interpretation, and conclusions presented.

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## Declaration of competing interest

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

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## Appendix

**Appendix 1**
Reflective Self-Diagnosis Template for Socio-Technical Enablers in the Preparatory Domain

| Enabler | | Key analytical element | Self-diagnosis question | Manifestation in practice | Underlying issues | Potential improvement actions | Indicative priority |
|---|---|---|---|---|---|---|---|
| **P1** | **Need-benefit alignment** | Significance | How does your digital technology initiative meaningfully align economic rationale (e.g., cost justification or return on investment) with ethical or environmental concerns? | | | | |
| | | Solutions for operational issues | How does your digital technology initiative address operational pain points of frontline staff while contributing to circular economy-related outcomes? | | | | |
| | | User benefits | How does your digital technology initiative provide tangible benefits that make users' work easier? | | | | |
| **P2** | **Time & resource allocation** | Staffing | To what extent have you assigned personnel with operational expertise and sufficient digital understanding to your digital technology initiative that contributes to circular economy outcomes? | | | | |
| | | Training | To what extent have you allocated sufficient time and provided adequate training (including repeated or intensive sessions) to prepare users for your digital technology initiative that contributes to circular economy outcomes? | | | | |
| | | User support | To what extent have you established expert user support to address urgent issues during the operation of your digital technology initiative that contributes to circular economy outcomes? | | | | |
| **P3** | **Engagement** | De-siloing | How have you coordinated different operational interests and fostered active information sharing across internal stakeholders? | | | | |
| | | Executive role-modelling | To what extent do executives visibly lead your digital technology initiative by example? | | | | |
| | | Employee buy-in | To what extent do frontline users genuinely buy into your digital technology initiative? | | | | |
| **P4** | **Operability** | Customisability | How do you maintain sufficient room for customisability in your digital technology initiative that contributes to circular economy outcomes, to accommodate company-specific processes and evolving business needs? | | | | |
| | | Usability | To what extent does your digital technology initiative ensure ease of use and accessibility for users with diverse characteristics (e.g., age, language, and digital proficiency)? | | | | |
| | | User affinity | To what extent do users feel positive about using your digital technology initiative that contributes to circular economy outcomes in their day-to-day work? | | | | |

**Appendix 2**
Reflective Self-Diagnosis Template for Socio-Technical Enablers in the Operational Domain

| Enabler | | Key analytical element | Self-diagnosis question | Manifestation in practice | Underlying issues | Potential improvement actions | Indicative priority |
|---|---|---|---|---|---|---|---|
| **O1** | **Management commitment** | Vision | How is the company's vision for the circular economy and digital transformation clearly articulated and owned by management? | | | | |
| | | Leadership | To what extent do senior executives lead decision-making for digital technology practices and create enabling conditions through strategic allocation of budgets and resources? | | | | |
| | | Systematic oversight | To what extent are digital technology practices structurally governed and systematically overseen | | | | |

(*continued on next page*)

**Appendix 2** (*continued*)

| Enabler | | Key analytical element | Self-diagnosis question | Manifestation in practice | Underlying issues | Potential improvement actions | Indicative priority |
|---|---|---|---|---|---|---|---|
| | | | within your company to support circular economy outcomes? | | | | |
| **O2** | **Holistic approach** | Systemic perspective | To what extent does your company adopt a systemic perspective that integrates economic activities with environmental considerations in digital technology practices that contribute to circular economy outcomes? | | | | |
| | | Reputation benefits | How does your company communicate brand and environmental values in the market to support acceptance of its digital technology initiative that contributes to circular economy outcomes? | | | | |
| **O3** | **Understanding & awareness** | Knowledge | How does your company build and share organisational knowledge about the circular economy and digital transformation among employees? | | | | |
| | | Accountability | How does your company link departmental and individual performance to circular economy-related outcomes to promote accountability and reflection? | | | | |
| | | Success stories | How does your company celebrate and disseminate internal success stories to create, sustain and reinforce momentum for its digital technology initiative that contributes to circular economy outcomes? | | | | |
| **O4** | **Organisational openness** | Innovation culture | How does your company foster a pioneering mindset and openness to change to support digital technology practices that contribute to circular economy outcomes? | | | | |
| | | Executive accessibility | How does your company ensure executive accessibility and reduce communication barriers to support digital technology practices that contribute to circular economy outcomes? | | | | |
| **O5** | **Collaboration** | Partnership | To what extent does your company strategically develop external partnerships through proactive information sharing to support informed decision-making in digital technology practices that contribute to circular economy outcomes? | | | | |
| | | External expertise | To what extent does your company leverage external expertise to enhance data analysis, shared understanding and the operation of digital technology practices that contribute to circular economy outcomes? | | | | |
| **O6** | **Continuous improvement** | A culture of Kaizen | How does your company embed a culture of Kaizen to support digital technology practices that contribute to circular economy outcomes? | | | | |
| | | Legacy practice reframing | How does your company encourage departments and employees to critically re-examine operational processes in order to continuously improve and adapt digital technology practices that contribute to circular economy outcomes? | | | | |
| **O7** | **Data foundation** | Data collection | To what extent does your company collect operationally critical data in a comprehensive and consistent manner to support digital technology practices that contribute to circular economy outcomes? | | | | |
| | | Data consolidation | To what extent does your company consolidate internal data across departments to support digital technology practices that contribute to circular economy outcomes? | | | | |
| | | Data accuracy | How does your company enhance data accuracy in internal and external communication to reduce operational errors and support digital technology practices that contribute to circular economy outcomes? | | | | |

## Data availability

The data that support the findings of this study are not publicly available due to confidentiality and ethical restrictions associated with the study design and institutional ethics approval, as the data contain information that could compromise the privacy of research participants.

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