Industry 5.0 in Waste Management: Uncovering the Dynamic Capabilities Behind the Transition

Maria Vincenza Ciasullo[*], *Miriana Ferrara*[**]

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Abstract

Industry 5.0 represents a transformative paradigm that addresses disruptive megatrends by calling for a human-centred approach and sustainability orientation. Despite growing academic interest, little is known about how organisations are transitioning towards this innovative strategical posture, particularly in the service businesses. The study addresses this gap by investigating the dynamic capabilities that waste management organisations must activate to undertake the aforementioned transition. Drawing on the Dynamic Capabilities Theory and a qualitative multiple-case study conducted on three Italian waste management firms, data were collected through 18 semi-structured interviews and archival sources and analysed by using the Gioia methodology. The results reveal three aggregate dimensions of capability such as: Waste Ecosystem Scanning Capability; People-Technology Orchestration Capability; Smart Waste Cycle Reconfiguration Capability. All together, these capabilities constitute an integrated architecture through which organisations perceive environmental complexity, orchestrate technological and human resources, and reconfigure their strategic, operational, and relational processes.

Keywords: Industry 5.0; Dynamic Capabilities; Waste Management; Sustainability; Human-centricity; Gioia Methodology.

[*] Full Professor, Department of Management and Innovation Systems, University of Salerno, Salerno, Italy; Faculty of Business, Design and Arts, Swinburne University of Technology, Kuching, Malaysia. Email: mciasullo@unisa.it. ID ORCID: 0000-0003-2052-551X.
[**] Postdoctoral researcher, Department of Management and Innovation Systems, University of Salerno, Salerno, Italy. Email: mferrara@unisa.it ID ORCID: 0009-0000-5310-8849

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Sommario

L'Industria 5.0 rappresenta un paradigma trasformativo che affronta i megatrend dirompenti promuovendo un approccio centrato sull'essere umano e orientato alla sostenibilità. Nonostante il crescente interesse accademico, si sa ancora poco su come le organizzazioni stiano effettuando la transizione verso questa innovativa postura strategica, in particolare nel settore dei servizi. Questo studio colma tale lacuna indagando le capacità dinamiche che le organizzazioni operanti nella gestione dei rifiuti devono attivare per intraprendere la suddetta transizione. Basandosi sulla Dynamic Capabilities Theory e su uno studio qualitativo multi-caso condotto in tre imprese italiane di gestione dei rifiuti, i dati sono stati raccolti attraverso 18 interviste semi-strutturate e fonti documentali, e analizzati mediante la Gioia Methodology. I risultati evidenziano tre dimensioni aggregate di capacità: Waste Ecosystem Scanning Capability, People-Technology Orchestration Capability, Smart Waste Cycle Reconfiguration Capability. Nel loro insieme, tali capacità costituiscono un'architettura integrata attraverso la quale le organizzazioni percepiscono la complessità ambientale, orchestrano risorse tecnologiche e umane e riconfigurano i propri processi strategici, operativi e relazionali.

Parole chiave: Industry 5.0; Dynamic Capabilities; Waste Management; Sustainability; Human-centricity; Gioia Methodology.

1. Introduction

The last decades have been characterized by transformative megatrends that have impacted and revolutionized the business landscape (Ciasullo *et al*., 2024; Naughtin *et al*., 2024). High economic instability, social disruptions, environmental concerns, technological innovations and digitalization drove businesses' profound transformations, by calling for a new evolutionary paradigm able to face the actual unstopping and vulnerable socio-economic context. At this regard, Industry 5.0 has arisen as a potential strategic approach that balances human needs, environmental and social issues, by also giving relevance to businesses' survival in the competitive environment. It has been defined for the first time by the European Commission (EC) in 2021 as the power of industry to achieve societal goals beyond jobs and growth, to become a resilient provider of prosperity, by making production respect natural environment boundaries and placing the wellbeing of workers at the center of the production process (Breque *et al*., 2021). Moreover, unlike Industry 4.0, Industry 5.0 emerges as the combination of advanced technologies for addressing social and environmental issues. In other words, it calls for the reshape of firms' directionality towards a sustainable technological transformation, for which the objective is not only to achieve efficiency and optimization, but also the creation of a human-centered, sustainable, and resilient business value (Montera *et al*., 2026; Renda *et al*., 2021). In this regard, Destouet *et al*. (2023) discussed how human-robot collaboration assumes a key role in improving work efficacy and worker well-being, reducing errors, and increasing production flexibility; Ciasullo and Ferrara (2025) highlighted the implications of Industry 5.0 for humans and social and environmental aspects; Ghobakhloo *et al*. (2022) depicted the opportunity to encourage recycling, remanufacturing, and resource reutilization.

Despite the growing scholarly interest in Industry 5.0, the existing body of managerial literature, as highlighted by Ciasullo and Ferrara (2025), has predominantly investigated this paradigm in the manufacturing industry, where the integration of humans together with the environmental and social values and advanced technologies is immediately observable (Ghobakhloo *et al*., 2024a). Consequently, a limited attention has been paid to the service industry. Yet, the growing relevance of personalized services, human-centric approaches, and sustainable practices increasingly call for a deeper understanding of how Industry 5.0 principles can be meaningfully transposed into service contexts.

Emerging contributions have begun to explore this trajectory in service business such as hospitality (Hussain *et al*., 2023), healthcare (Gomathi *et al*., 2023), and education (Hashim *et al*., 2024), examining how service delivery is reshaped in terms of customer satisfaction, patient-centricity, student well-being, sustainable tourism, and healthcare resilience. Among service industries, the waste management stands out as a particularly compelling yet underexplored domain for the application of Industry 5.0. Indeed, this service context suffers from the upcoming mega trends which have brought a significant rise in waste generation. Particularly, the combination of rapid population expansion, accelerated industrial development, and increasing urbanization has contributed to increasing annual municipal solid waste production in urban areas worldwide (Das *et al*., 2019). Municipal solid waste generation is predicted to grow from 2.1 billion tonnes in 2023 to 3.8 billion tonnes by 2050[1]. The UN Environmental Programme outlined that waste has been of the main drivers in contributing to worldwide environmental urgencies, since it played a role in climate change, biodiversity loss and pollution. More in-depth, the Global Waste Management Outlook 2024 pointed out that transporting, processing and disposing of waste generate CO_2 and other greenhouse gases and airborne pollutants that contrib-

[1] Global Waste Management Outlook 2024 by UN Environmental Programme (UNEP) available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/44939/global_waste_management_outlook_2024.pdf?sequence=3

ute to climate change and can have significant negative effects on human health and the environment. Against this backdrop, Industry 5.0 emerges as a strategic opportunity for the waste management sector, since the integration of advanced technologies with sustainability-oriented and human-centric practices may offer a viable pathway for addressing the sector's most pressing operational and environmental challenges (Zoumpoulis *et al*., 2024). However, academic inquiry at the intersection of Industry 5.0 and waste management remains nascent, with only a limited number of contributions beginning to explore this research area (Mesjasz-Lech, 2023; Govindaraj *et al*., 2024).

Beyond the sectoral gap, a deeper theoretical lacuna emerges from the existing literature. Current studies have predominantly focused on describing the outcomes of Industry 5.0 (Ciasullo and Ferrara, 2025; Ghobakhloo *et al*., 2023) while neglecting the managerial processes through which firms actually transition towards this paradigm. In particular, scant scholarly attention has been devoted to understanding which capabilities firms need to activate to pursue an Industry 5.0 trajectory, and how these capabilities are mobilized, combined, and embedded within organizational routines and processes. This gap becomes especially pronounced in the service industry, where the interplay between human actors, sustainability relevance, and digital technologies assumes a configuration that differs substantially from the manufacturing context.

Against this backdrop, this study aims to uncover the capabilities that must be activated to actualize Industry 5.0 in the waste management sector. Theoretically, the study draws on the Dynamic Capabilities approach (Teece *et al*., 1997; Teece, 2007), since it offers a robust framework for examining how organizations sense environmental opportunities, seize relevant resources, and reconfigure business processes in response to changing conditions. Methodologically, a qualitative approach through a multiple case study (Yin, 2018) is adopted by involving three Italian waste management firms. Data analysis follows the Gioia methodology (Gioia *et al*., 2013), enabling an inductive theory-building approach capable of capturing the organizational complexity and interpretive richness inherent in the phenomenon under investigation.

The paper is structured as follows. After the introduction, Section 2 analyzes the study's theoretical background; Section 3 depicts the research design and the implemented methodology for the empirical analysis. Follow Sections 4 and 5, in which the achieved results are presented and discussed; and theoretical and practical implications are considered. Lastly, in Section 6, conclusions, and possible future research are outlined.

2. Literature review and theoretical background

2.1 Industry 5.0: a look into the waste management sector

The conceptualization of Industry 5.0 has generated considerable academic debate, structured around two main interpretive positions. A first strand frames it as an incremental evolution of Industry 4.0: building on its technological foundations, Industry 5.0 expands the scope of industrial transformation toward social and environmental goals (Xu *et al*., 2021; Ghobakhloo *et al*., 2022). A second strand, by contrast, emphasizes the technological character of the paradigm, pointing to human-robot symbiosis (Nahavandi, 2019; Maddikunta *et al*., 2022), the emergence of symbiotic factories (Longo *et al*., 2020), and highlighting the high sophisticated technologies coming with Industry 5.0. Rather than treating these positions as mutually exclusive, the present study, by adopting an integrative view, conceptualize Industry 5.0 as an *incremental revolution* that inherits from Industry 4.0 advanced and digitized technologies while reorienting them toward human-centred, environmentally and socially sustainable value creation. In other words, going beyond the technocentric nature of Industry 4.0, the latter paradigm emphasizes a human-centric approach that tends towards a logic of sustainability and organizational resilience, for which digital technologies represent tools that facilitate the achievement of organizational objectives (Ciasullo *et al*., 2023).

In the waste management sector, despite the number of studies is limited, Industry 5.0 has been mostly conceptualized according to the technological revolutionary approach, thereby adopting an engineering perspective and focusing on the enabling role of digital technologies, such as IoT, AI, smart bins, blockchain, and robotics, in optimizing waste management processes.

In this regard, recent contributions have predominantly emphasized the infrastructural and algorithmic dimensions of this transition. Zoumpoulis *et al*. (2024) and Govindaraj *et al*. (2024) converge in situating smart bin technology as a foundational innovation, but differ in scope. The former proposes a novel concept design that combines advanced sensing, automation, and data analytics to address the limitations of existing commercial solutions and enhance efficiency in technology-driven urban waste management; the latter adopts a broader evolutionary perspective, tracing the trajectory of urban waste management from rudimentary disposal methods to sophisticated, sustainability-oriented circular systems through the lens of smart bin innovation, and demonstrating how Industry 5.0 principles can be operationalized at the level of waste collection infrastructure. Anitha (2025) extends this technical trajectory further, integrating edge-AI smart bins, digital twin simulation, and graph-theoretic routing into a next-generation waste ecosystem, while Chauhan *et al*. (2026) similarly emphasize the operational integration of AI, machine learning, and IoT for real-time monitoring and automated classification, illustrating their direct relevance for AI-enabled operational systems in European urban environments.

Although these contributions recognize the relevance of Industry 5.0 to waste sector, the engineering-oriented perspective mostly focuses on the technical facets such as infrastructure and related design by stressing the specific outputs linked to the implementation of digital technologies. In other words, these studies operationalize Industry 5.0 at the level of technical systems and process outcomes, with no reflection about how organisations transition towards Industry 5.0 in terms of resources to mobilize, strategic choices to make, and internal transformations to undergo. Understanding it exclusively through a technological lens risks reducing a complex and transformative phenomenon to a set of tools, thereby obscuring the strategic, operative and tactical business processes that give meaning to those tools. Therefore, according to the incremental revolution view proposed, the Industry 5.0 paradigm requires a strategic posture able to sustain technologies with social and environmental concerns along with a human-centric approach, then calling for a deep analysis to understand how to integrate and combine these elements. More in depth, it is necessary to understand how organizations strategically manage the transition to Industry 5.0, uncovering both the resources that must be mobilized and the capabilities that must be activated to make such a transition possible.

2.2 A Dynamic Capability Approach

To meet the objective of the study, it relies on the Dynamic Capabilities Theory (DC). This theoretical approach explains how firms sustain innovative business value in complex and rapidly changing environments (Teece *et al*., 1997). Dynamic capabilities are defined as the ability of an organization to integrate, build, and reconfigure internal and external competencies in response to shifting environmental conditions (Teece, 2007), and have been more recently extended to encompass the capacity to ensure robustness and recoverability from disruptions (Teece, 2023). Unlike ordinary capabilities, which concern the efficient execution of existing routines, dynamic capabilities are inherently future-oriented: they enable firms to anticipate strategic needs, identify emerging opportunities, and proactively reshape their resource base in alignment with long-term organizational goals.

According to the seminal literature (Teece, 2007), DC provides three interrelated capabilities: sensing, seizing, reconfiguring. Sensing refers to the continuous scanning, monitoring, and interpretation of signals from the external environment, that enable proactive anticipation and informed decision-making (Teece, 2017). Seizing encompasses the rapid mobilization and allocation of resources, in response to the opportunities identified through sensing, implying both decisional agility and the capacity to configure assets, partnerships, and organizational structures in ways that translate opportunity recognition into value creation (Teece, 2007). Reconfiguring involves the adaptive transformation of the firm's operational and organizational processes, ensuring long-term competitiveness by enabling firms to evolve its routines, cultural orientations, in response to both internal learning and external disruption (Teece, 2023). All together those capabilities set up a dynamic, iterative cycle through which firms not only respond to environmental change but actively shape their corporate capacity to do so overtime (Teece, 2017).

Since Industry 5.0 represents a complex transition, which simultaneously demands technological investment, human capital development, and environmental and social sensitivity, DC fits with the aim to understand the resources and the capabilities that are mobilized to make this transition real. Indeed, in the stream of literature related to Industry 5.0, DC has been already adopted in terms of useful theoretical perspective. For example, Mohammed *et al*. (2025) adopted it to identify the main capabilities that drive inner business resilience in the context of supply chains; Beta *et al*. (2025) highlighted how cultivating DC can enable governments to innovate responsibly and effectively under the Industry 5.0 paradigm; Modgil *et al*. (2025) uncovered the right capabilities for supply chain professionals in the context of the upcoming paradigm.

However, these contributions tend to address specific and partial dimensions of Industry 5.0. For example, Mohammed *et al*. (2025) concentrated primarily on its technological components, while Modgil *et al*. (2025) focused on the human capability dimension, thereby leaving room for a more comprehensive understanding of the full spectrum of capabilities that firms should activate to transition towards Industry 5.0 in its whole. Accordingly, the study explores sensing, seizing, and reconfiguring capabilities that waste management organizations nurture to navigate the complexity of the Industry 5.0 transition.

3. Methodology

3.1 Research design and context

To detect the dynamic capabilities activated to embrace Industry 5.0 in waste management this study employs a qualitative, multiple-case study design. This approach is established in management literature as a steady methodology that provides insights into an unexplored real-life phenomenon that quantitative methods are not able to extract (Hyett *et al*. 2014, Thomas 2011), thereby capturing the intricacy of the object of study.

The multiple case study analysis is focused on three Italian waste management firms. Italy has been chosen as the research context primarily because it is characterized by a supportive institutional context, that has been implementing initiatives related to circular economy to recycle waste (i.e., and investments of € 27.7 billion for the development of renewable energy and the improvement of the circular economy, PNRR). These efforts translate in Italy as the first ranking country among the five largest European economies in terms of circular economy performance, with the waste management sector as the main driver of this result (Sustainable development foundation, 2024). Moreover, with a municipal waste recycling rate of 53.3% (higher than the EU average of 49.1%) Italy demonstrates a mature operational waste management infrastructure (ISPRA Report, 2024).

The unit of analysis is the organization, with each of the companies treated as an embedded case, encompassing multiple respondent perspectives across various organizational functions (Yin, 2018). The case studies were selected according to a non-probabilistic, purposive sampling approach (Stake, 1995), oriented toward informational richness and cross-case comparability. Indeed, each case was selected for its ability to provide revealing and in-depth evidence of an emerging phenomenon (Eisenhardt and Graebner, 2007). This sampling strategy was guided by the following screening parameters (Rapley, 2014): (1) core business in the waste management sector, (2) being based in Italy, (3) having implemented advanced technologies in the last five years, (4) owning sustainability certificates (e.g., ISO 14001, EMAS), (5) having implemented human-centric practices (e.g., ISO 45001; SA8000). Given the strictness of these criteria and the still-emerging nature of the phenomenon under investigation, three organizations were selected. To maintain confidentiality, the names of the organizations were anonymized using symbols and progressive numbers. Appendix A describes the main characteristics of the involved organizations.

3.2 Data collection

Both primary and secondary data was collected over a period of six months (September 2025 – February 2026). Primary data was collected through qualitative interviews (Kvale and Brinkmann, 2009). To ensure that key informants covered a wide range of knowledge (Eisenhardt and Graebner, 2007). They were recruited in diverse business units. In total, 18 interviews were held across the three case organizations, with 6 interviews conducted each (Table 1). Interviewees were selected through a purposive sampling that required the following criteria: (1) having 10 years of seniority; (2) having a good knowledge of waste management processes. All the interviews were open-ended and semi-structured, so that participants were freely able to respond and also to raise whatever issues they considered important and give the researchers the flexibility to probe any matters that needed to be clarified (Silverman, 2013). Each respondent was first telephonically and informally informed about the scope and the focus of the discussion. In this conversation, they could get more insights into the interview process thereby enhancing their understanding of the topic. Furthermore, a cover letter was sent through an email that requested respondent consent and informed them about the anonymity and confidentiality of data so the respondents would be open to disclosing information beneficial for the study. Each interview lasted between 30 and 45 minutes each. Before organizing the series of interviews, a pilot test among 3 respondents was implemented to identify flaws, possible misunderstandings and weaknesses of the interview design (Kvale, 2007). The interview protocol was organized to extract relevant insights into the transition towards Industry 5.0, by investigating the main capabilities that the firms activated (Castillo-Montoya, 2016; Turner III, 2010). Due to the respondents' geographical distance, the interviews with the selected key informants, were conducted via Zoom platform, digitally recorded and transcribed verbatim to ensure no discrepancy was present (Yin, 2015).

Secondary data was collected to boost primary data and triangulate them (Patton, 2015). They consisted of archival information (e.g., reports, corporate websites, sustainability reporting, strategic plans), local and national waste management reports, and institutional documents. The triangulation process was implemented through the systematic cross-reference with interview transcripts to corroborate emerging codes, ensuring that themes identified in informants' accounts were consistent with documentary evidence. Also, secondary data were employed to validate the findings of the study by verifying their alignment with the organizations formally declared strategies and initiatives.

3.3 Data analysis

Given that the aim of the study was to inductively investigate how waste management firms implemented Industry 5.0 in terms of dynamic capabilities, data were analyzed according to the logic of Gioia Methodology (Gioia *et al*., 2013). Indeed, this approach allowed a theoretically grounded-empirically informed approach engaging with an abductive logic (Magnani and Gioia, 2023).

Data analysis was conducted collaboratively by the entire research team, undertaking three iterative and interrelated stages.

First, each interview was read several times to develop a deep understanding of the organizational practices, technological initiatives, and transformation processes associated with the transition toward Industry 5.0 in the waste management context. At this stage, archival documents were taken into account to deeply understand and corroborate the informants' declarations.

Second, the study proceeded with the coding process, characterized by an iterative and abductive logic. To enhance analytical rigor and ensure inter-coder reliability, each researcher independently conducted the initial coding, after which coding outcomes were systematically compared and discussed within the research team. This autonomous coding procedure also helped reduce the risk of individual researcher bias throughout the analysis process (Gioia *et al*., 2013). Agreement was pursued through an iterative, consensus-based process: each disagreement in coding was discussed collectively until convergence was reached, by aligning interpretive and abductive logic underpinning the Gioia methodology (Gioia *et al*., 2013; Magnani and Gioia, 2023).

Initially, researchers identified recurrent themes, practices, and expressions emerging from the interviews, particularly those related to the enabling dynamic capabilities within waste management firms. The analysis moved progressively from raw qualitative evidence to increasingly abstract conceptualizations through the identification of first-order categories, grounded in informants' terms and interpretations. Subsequently, second-order categories were developed by systematically comparing empirical insights with prior literature on DC. These second-order themes enabled a more theory-centered interpretation of the empirical evidence, capturing how organizations develop sensing, seizing, and reconfiguring capabilities to support human-centric, resilient, and sustainable trajectories.

Finally, aggregate dimensions were identified by combining empirically grounded first-order concepts with theoretically informed second-order themes. At this level, archival documentation were used to validate and triangulate informants' responses. For example, statements regarding the reorientation of strategic priorities towards sustainability (e.g., SRM3) were cross-checked against the organizations' publicly available strategic plans and sustainability reports, confirming that such priorities were also formally embedded in official documentation, avoiding the possibility of relying only on individual perceptions. This highest level of abstraction enabled the researchers to conceptualize the dynamic capabilities underpinning the transition toward Industry 5.0 in waste management organizations.

Table 1: Respondents' information

ID	*Type of actor*	*Structure characteristics*
SRM1	Strategic and risk Manager	O1 is a large Italian waste treatment and disposal firm. It manages approximately 100 waste treatment facilities in the North and Center, including landfills, waste-to-energy plants, anaerobic digestion units, and waste sorting facilities, processing over 7 million tonnes of waste annually.
SM1	Sustainability Manager	
IM1	Innovation Manager	
HR1	HR Manager	
OM1	Operational Manager	
NM1	Network Manager	
SRM2	Strategic and risk Manager	O2 is one of Italy's largest waste management companies, operating across the entire waste management value chain, from collection to material and energy recovery, with over 12,000 employees and nationwide presence.
SM2	Sustainability Manager	
IM2	Innovation Manager	
HR2	HR Manager	
OM2	Operational Manager	
NM2	Network Manager	
SRM3	Strategic and risk Manager	O3 is a leading firm operating across Northwestern Italy and beyond, active in providing environmental services. Through its dedicated environmental subsidiary, the company serves over 3 million inhabitants with waste collection and treatment services, achieving a separate waste collection rate of 72.1% in 2024, significantly above the national average.
SM3	Sustainability Manager	
IM3	Innovation Manager	
HR3	HR Manager	
OM3	Operational Manager	
NM3	Network Manager	

4. Findings

This section presents the results of the empirical analysis according to a progressive and abductive logic, which identifies and conceptualizes the capabilities activated to embrace a behaviour inspired by Industry 5.0 in waste management organizations. Figure 1 shows the data structure of the methodological systematic process followed as described in the previous section.

4.1 Waste ecosystem scanning capability

Waste ecosystem scanning capability is the first aggregate dimension conceptualized in this analysis. It describes the capacity of waste management organizations to continuously read and interpret the external environment in its regulatory, environmental and social dimensions. This capability represents the foundational sensing mechanism through which firms recognize the urgency of transitioning towards Industry 5.0 and identify the strategic direction needed to make it possible. Three second-order codes underpin this dimension: Institutional and regulatory sensing, Environmental urgency sensing, and Societal consciousness.

Institutional and regulatory sensing captures the organization's ability to monitor and anticipate regulatory pressures at both European and national levels, translating normative mandates into strategic orientations. The firms under study demonstrated a proactive rather than reactive approach to regulatory compliance, treating policy frameworks such as the European Green Deal, the Circular Economy Action Plan, and the UN Agenda 2030 not as external constraints but as strategic enablers. As SRM2 stated: "*European regulations are not a burden for us, they are a roadmap. We read them carefully and use them to anticipate where the sector is going*". Similarly, said SRM3"*Following European standards is not easy, but we strongly believe it is necessary to be aligned with them, this is why we have institutionalized a business unit dedicated to regulatory monitoring*".

Environmental urgency sensing reflects the organization's ability to keep updated with the environmental risks that are linked to such sensitive sectors such as waste management. The organizations demonstrated a clear recognition of the mounting pressures generated by increasing waste volumes, greenhouse gas emissions from transportation and disposal, soil and water contamination risks, and the growing inadequacy of traditional landfill-based models. OP3 declared: "*We know very well our sector, the waste generation is more and more high. We cannot keep responding with the* *same tools and the same logic – the environmental pressure forces us to innovate, not incrementally but structurally*". In the same logic, SRM3 affirmed: "*We know that our activity can produce effects for the society in general. We are committed to be always updated regarding waste generation trends, this allows us not to be late*".

Societal Consciousness captures the organization's awareness of its responsibilities towards the communities it serves, and its recognition that waste management practices have direct and tangible consequences on citizens' health, quality of life, and societal well-being. The firms demonstrated a genuine orientation towards community welfare that extended beyond service delivery metrics, framing citizens not merely as passive users but as active actors whose well-being sets a strategic priority for them. As IM2 remarked: "*We operate in people's neighborhoods, we affect the air they breathe and the quality of their environment. The health of the community is not a secondary consideration; it is at the center of everything we do*". This societal awareness also translated into a recognition that community engagement is not optional but structurally necessary for achieving sustainability objectives in waste management. NM1 affirmed: "*Citizens are our most important partners in this transition. Without their awareness and active participation, no technology or regulation will be sufficient to address the waste challenge we are facing*".

4.2 People-technology orchestration capability

The second aggregate dimension emerging from the analysis is the People-Technology Orchestration Capability. It describes the capacity of waste management organizations to deliberately mobilize, combine, and integrate technological and human resources in a synergistic manner to pursue social and environmental objectives. This capability represents the strategic orchestration of technologies and humans simultaneously, recognizing that the transition towards Industry 5.0 requires the joint activation of digital assets and human potential. Three second-order codes underpin this dimension: Digital and Technological Resource Mobilization, Human-Centric Resource Activation, and Strategic Ecosystem Building.

Digital and technological resource mobilization captures the organization's capacity to identify, invest in, and deploy enabling digital technologies. The firms under study demonstrated a sophisticated approach to technology adoption, moving beyond isolated tool implementation towards the construction of integrated digital ecosystems and smart infrastructures. Investments in IoT sensors, AI-powered sorting systems, blockchain platforms, and smart infrastructure were framed not as efficiency measures but as foundational assets enabling a new operational logic inspired by environmental responsibility. As OP2 stated: "*Investing in technology is not about doing the same things faster – it is about doing fundamentally different things. IoT and AI allow us to build a waste management system that is responsive, transparent, and genuinely sustainable*".

Human-centric resource activation captures the organization's capacity to develop, engage, and empower human resources – both internal and external – as active co-creators of the Industry 5.0 transition. This second-order code manifested in waste management through three interconnected practices: workforce upskilling, worker safety enhancement through technology, and community co-creation. The firms demonstrated a genuine commitment to developing their employees' digital competencies. As HR2 observed: "*We invested heavily in training our people on digital tools. Technology without people who understand it and believe it is just expensive equipment*". Worker safety emerged as a particularly salient dimension of human-centricity in waste management, given the physical risks inherent in waste operations. The adoption of robotics, automation, and wearable monitoring technologies was explicitly framed as a human welfare investment rather than a purely operational efficiency measure. As OP1 stated: "*Robots in our disposal facilities are not replacing our workers – they are protecting them. No human being should be exposed to hazardous waste if a machine can do it safely*". Finally, community co-creation emerged as an extension of human-centricity beyond organizational boundaries, with firms actively engaging citizens as participants in the waste management system through digital platforms, and awareness campaigns. As NM3 remarked: "*Citizens are not the end point of our service – they are part of the system. We developed our app to be empowered by their observations*".

Strategic ecosystem building reflects the organization's capacity to mobilize resources beyond its own boundaries, through the construction of strategic partnerships, cross-sector collaborations, and innovation ecosystems. The firms demonstrated a clear recognition that no single organization possesses all the capabilities required for a full Industry 5.0 transition in waste management, making ecosystem building a strategic necessity. Partnerships with technology startups, research institutions, municipalities, and European funding bodies were actively cultivated as sources of complementary resources. As NM1 noted: "*We developed a partnership with a digital start up because we needed a tailored IoT systems during the disposal process*". The creation of shared value emerged as the unifying logic of this ecosystem building activity, with firms increasingly designing their partnership strategies around the co-generation of economic, environmental, and social value. IM3 affirmed: "*Our partnerships are built around a common objective which is to create value for the territory*".

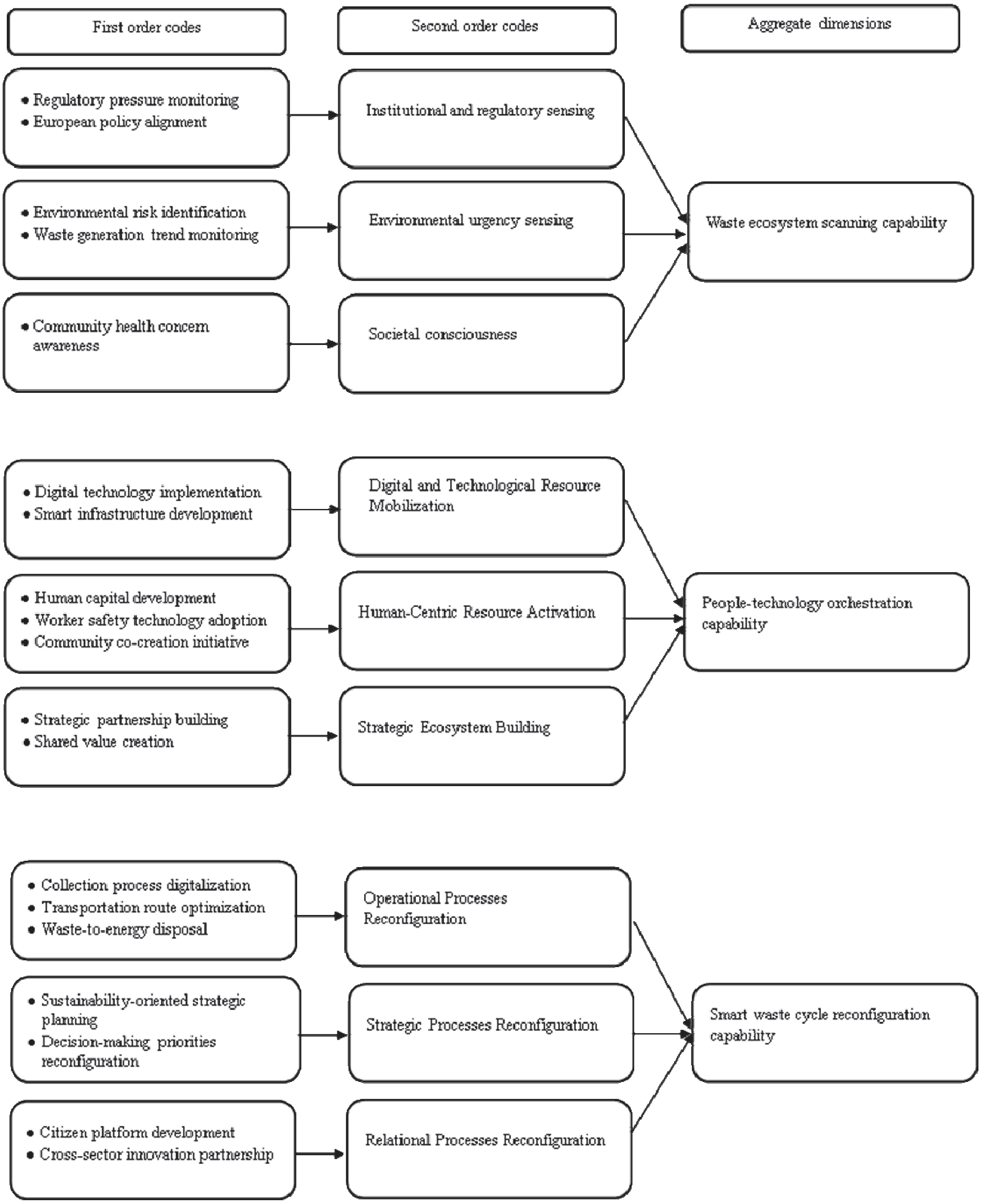
4.3 Smart waste cycle reconfiguration capability

Smart Waste Cycle Reconfiguration Capability is the third aggregate dimension emerging from the analysis. It describes the capacity of waste management organizations to transform their core operational, strategic, and relational processes in response to the sensing and seizing capabilities activated. This dimension represents the manifestation of how firms reconfigure their ways of operating, strategizing, and relating considering technological innovation, environmental urgency, and social responsibility. Three second-order codes underpin this dimension: Operational processes reconfiguration, Strategic processes reconfiguration, and Relational processes reconfiguration.

Operational processes reconfiguration captures the transformation of core waste management processes – collection, transportation, and disposal and recycling – through the integration of digital and smart technologies, bringing the emergence of new operational routines. The digitalization of waste collection emerged as the most visible manifestation of this reconfiguration, with smart bin networks replacing traditional fixed-route collection with demand-responsive systems activated by real-time waste level data. As OP1 stated: "*We no longer send trucks on fixed routes at fixed times. The system tells us where to go and when – based on actual data. This changes everything: efficiency, emissions, costs, and service quality all improve simultaneously*". Transportation processes underwent a parallel reconfiguration, with GPS tracking, IoT connectivity, and blockchain-based traceability enabling dynamic routing and end-to-end monitoring of waste flows. Also, disposal processes were similarly reconfigured, with firms developing long-term strategies to reduce landfill dependency in favor of waste-to-energy solutions and robotic automation. This reconfiguration reflected a fundamental shift in the treatment of waste, from a problem to be disposed of to a resource to be valorized. SRM1 affirmed: "*Our goal is to make landfill the last resort, not the default option. Waste-to-energy and robotics are the tools that make this possible, they allow us to extract value from waste while protecting our workers*".

Strategic processes reconfiguration reflects the transformation of the organization's planning, and business model logics in response to Industry 5.0 imperatives. This second-order code captures a fundamental shift in strategic orientation – from cost-minimization and short-term financial returns to long-term value creation anchored in sustainability, and circularity. As SRM3 affirmed: "*Our strategic plan looks completely different from what it was ten years ago. Sustainability is not a chapter at the end; it is the playground within which every strategic decision is made*". Similarly, a reconfiguration of decision-making processes was undertaken, by differently positioning the firms' priorities, and balancing economic returns with environmental and societal outcomes.

Figure 1: Data structure



Relational processes reconfiguration captures the transformation of the organization's relationships with its key external stakeholders. Citizen platform development emerged as the most visible expression of this relational reconfiguration, with digital tools enabling citizens to actively participate in waste management processes – reporting issues, tracking collection schedules, accessing recycling guidance, and exchanging reusable goods. NM3 stated: "*Our app transformed the relationship with citizens. They are no longer passive recipients of services; they are active participants in a circular system. That changes the nature of our organization fundamentally*". Cross-sector innovation partnerships further expanded the organization's relational ecosystem, with firms co-developing technological solutions, sharing knowledge, and accessing complementary resources through collaborations with startups, universities, and institutional actors. As NM3 noted: "*Our most important innovations did not come from inside our organization, they came from partnerships. Opening up to external knowledge and co-developing solutions with others is now a structural part of how we operate*".

5. Discussions and implications

This study uncovers the dynamic capabilities that waste management organizations activate to transition towards Industry 5.0. The empirical analysis, conducted across three Italian waste management firms, reveals three aggregate dimensions, such as Waste Ecosystem Scanning Capability, People-Technology Orchestration Capability, and Smart Waste Cycle Reconfiguration Capability. They collectively constitute the overarching capabilities to trigger the shift towards Industry 5.0.

Waste Ecosystem Scanning Capability emerges as the foundational sensing mechanism underpinning the transition. It is operationally nurtured by the institutionalization of dedicated organizational units (i.e., regulatory monitoring units), then reflecting the top management efforts in explicitly allocating organizational resources. Instead of functioning as a passive monitoring activity, this capability reflects an active, interpretive process through which organizations develop the ability of simultaneous considering and reading regulatory, ecological, and social signals from the external environment. In this direction, this capability configures as multi-dimensional. Therefore, differently from previous studies (Mohammed *et al.*, 2025; Modgil *et al.*, 2025), which have predominantly addressed sensing in terms of market or technological signals, the present one demonstrates that in socially and environmentally sensitive industries, sensing is inseparable from normative and societal dimensions, and, more specifically, from the governance structures that formalize and sustain it. In the context of waste management specifically, where operational activities have direct consequences on public health and territorial sustainability, sensing must also encompass civic and environmental responsibility.

People-Technology Orchestration Capability represents the core seizing mechanism through which organizations translate environmental awareness into actionable organizational transformation. In other words, it emerges that to meet environmental and societal issues, the firms both implemented technologies and valorized the role of humans. Indeed, technologies such as IoT infrastructures, blockchain, AI systems were integrated, while knowledge-based resources (e.g., workforce upskilling, community involvement, cross-sector partnerships) were mobilized to create the transformative value towards Industry 5.0. This orchestration requires top management to actively integrate resources investments in technological infrastructure and workforce development, indicating that seizing capability depends on a form of strategic leadership capable of sustaining a balanced technology-human approach over time. This finding resonates with the conceptualization of seizing capabilities (Teece, 2007), by showing that value creation arises not from the optimization of technological or human assets in isolation, but from their orchestrated integration. The orchestration, finally, emerges as a distinctive conceptualization of the seizing capability in service contexts, which differs from the technology-centered seizing logic which is central in manufacturing-oriented studies (Ghobakhloo *et al*., 2022; Ghobakhloo *et al*., 2024a).

Smart Waste Cycle Reconfiguration Capability captures the multi-level transformation that occurs once sensing and seizing capabilities have been activated. The reconfiguration unfolds simultaneously across operational, strategic, and relational dimensions, distinguishing Industry 5.0 transition from simple process digitalization. Operationally, the shift from fixed-route collection to demand-responsive smart systems and from landfill-based disposal to waste-to-energy and robotic automation reflects a fundamental redesign of the waste management value chain. Strategically, sustainability moves from a peripheral reporting requirement to the organizing logic of long-term planning. This approach represents a governance-level shift, whereby top management repositions sustainability as the organizing principle of strategic decision-making rather than a compliance outcome (Helfat and Peteraf, 2015). Relationally, citizens and external partners are repositioned from passive service recipients to active co-creators within a circular ecosystem, a transformation coordinated through structured mechanisms of stakeholder engagement. This multi-level reconfiguration aligns with Teece's (2023) extended conceptualization of reconfiguring capabilities as encompassing cultural and relational transformation and enriches it by grounding it empirically in a service industry context.

The study presents both theoretical and managerial implications.

First, it extends the DC Theory reconceptualizing each of its constitutive capabilities for navigating the transition towards Industry 5.0. Sensing is shown to be multidimensional, going beyond isolated market or technological signals. Seizing is reconceptualized as an orchestration logic that jointly mobilizes technological and human resources. Reconfiguring, in turn, is shown to unfold simultaneously across operational, strategic, and relational dimensions. Second, it contextualizes the dynamic capabilities in a context-specific domain (i.e., waste management). This extends prior contributions (Mohammed *et al.*, 2025; Modgil *et al.*, 2025; Beta *et al.*, 2025), which have addressed partial or sectoral dimensions, towards a more comprehensive and integrated understanding. Third, it demonstrates that sensing, seizing, and reconfiguring are activated through governance mechanisms that reshape the allocation of organizational resources, the human-technology combination and the collaboration with stakeholders. In this direction, top management plays a central role in supporting the transition towards Industry 5.0. Indeed, the whole process is the result of governance deliberate choices, from the organizational structure to the strategic decision-making process. This reading resonates with, and extends, Teece's (2007) original formulation, pointing towards a more governance-sensitive understanding of how dynamic capabilities are activated and sustained. Fourth, it proposes a dynamic perspective of how the transition is triggered towards Industry 5.0, overcoming previous studies that mostly described Industry 5.0 in terms of outcomes (Ghobakhloo *et al.*, 2023). Fifth, it responds to the call for broader service-sector investigation of Industry 5.0 (Ciasullo and Ferrara, 2025), generating context-sensitive insights that challenge the manufacturing-centric assumptions pervading the existing literature.

Managerially, the study provides actionable insights to businesses. First, they should institutionalize environmental scanning as a dedicated strategic business area to nurture that proactive behaviour that allow managers to be constantly updated with environment regulatory trends, and community signals. Therefore, they could create specific teams addressing it. Second, managers must invest in people and technology simultaneously. The orchestration logic emerging from the data shows that digital tools generate value only when paired with workforce upskilling and worker safety initiatives. Accordingly, establishing partnerships emerges as a relevant condition for sustaining the transition over time.

Third, managers should recognize users and citizens as embedded co-actors in creating value. Indeed, through human-centric digital platforms, the firm is able to collect real-time behavioral data that feedback into sensing and reconfiguration processes, creating a virtuous cycle between community involvement and organizational learning.

6. Conclusions and limitations

This study provided a granular exploration of the dynamic capabilities that waste management organizations must activate to transition toward Industry 5.0. A qualitative multiple case study of three Italian firms has been conducted by implementing the Gioia methodology. Three aggregate dimensions were identified: the Waste Ecosystem Scanning Capability, the People-Technology Orchestration Capability, and the Smart Waste Cycle Reconfiguration Capability.

Although this research provides valuable insights into Industry 5.0 core capabilities, there are some limitations. First, the focus on three main Italian waste management firms limits the generalizability of the findings, both because the study considers one geographical context and firms that are embracing this transition towards Industry 5.0. Future studies could perform comparative analysis across different national contexts (considering also emerging economies) thereby enriching the understanding of how institutional environments influence capability development. Moreover, comparative studies could assess the differences between firms that are transitioning and those who are not. In this sense, also longitudinal studies could be employed to track capabilities evolution over time. Second, the reliance on semi-structured interviews and archival data as the sole sources of evidence may introduce collection biases that constrain the depth of the findings. Future research adopting a mixed-method approach and a broader sample would therefore strengthen the robustness and comprehensiveness of the emerging understanding of Industry 5.0 capabilities.

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Appendix A

Organization 3	Characteristics of firms	Organization 1	Organization 2
IoT and AI integration for smart waste management; AI sensor for waste composition analysis; AI computer vision systems for sorting cabin material analysis	**Enabling Technologies**	AI for recyclable material identification and collection route optimization; IoT platform for real-time data collection from sensors and truck-mounted cameras; Generative AI across 150 use cases.	IoT-enabled waste collection; AI-powered waste-to-energy plants; data analytics platforms for circular economy management; smart city digital infrastructure
Collection (smart bins, demand-responsive systems); transportation (route optimization); disposal (sorting automation); recycling (AI-driven sorting)	**Processes Reconfigured**	Collection (dynamic data-driven routing); transportation (IoT-based traceability); disposal (AI sorting, waste-to-energy); recycling (AI material identification)	Collection, transportation, disposal (waste-to-energy), recycling (material recovery), smart city services
Project for disability inclusion; mandatory sustainability training programs for all staff levels, ISO 45001; SA8000	**Human-centricity- Worker**	Top Employer certification for 17 consecutive years; global Top 10 Diversity & Inclusion Index; robotics for worker protection in disposal facilities, ISO 45001; SA8000	Worker safety programs; robotics to reduce worker exposure to hazardous waste, ISO 45001; SA8000
App for separate waste collection, door-to-door calendar, collection center locator, geo-referenced photo reporting, environmental news, kitchen waste recipes, service desk locator	**Human-centricity-Citizen**	App with 950,000+ downloads: barcode scanner for recycling guidance, door-to-door collection calendar, geolocation of ecological stations, photo-reporting of abandoned waste, bulky waste collection booking, Alexa voice integration	Free app for citizens collection calendar, separate waste collection guidance, anomaly reporting, ecological platform locator, bulky waste collection booking
72.1% separate waste collection rate (vs. 67% national average); ESG objectives to 2040; agrivoltaic and biogas from organic waste, ISO 14001, EMAS	**Sustainability – Environmental**	Net Zero 2050 target; -35% CO2 by 2029; 77.7% separate collection target by 2027; biomethane production from organic waste; plastic recycling, ISO 14001, EMAS	7 billion euro circular economy investments by 2035; 6.6 million tonnes of waste managed annually; material and energy recovery as core model, ISO 14001, EMAS
Loyalty program with gamification for citizen engagement in urban regeneration and Energy Bank donations	**Sustainability – Social**	Creating Shared Value as core business model; environmental education programs in schools	Community transparency initiatives around waste-to-energy plants; shared territorial value; institutional partnerships for service co-design
AI technology specialists for computer vision sorting systems; European Investment Bank for circular economy development; universities and research centers; municipalities for smart waste infrastructure	**Strategic Collaborations**	Generative AI start up; enterprise digital transformation, international organization for recycled plastic pipes	European Investment Bank for circular economy investments; technology startups for innovation; municipalities for service co-design; waste-to-energy technology partners